# MODERN PRACTICE IN MINING

# MODERN PRACTICE IN MINING

## VOL. I

# COAL

## ITS OCCURRENCE, VALUE, AND METHODS OF BORING

BY

R. A. S. REDMAYNE,
M.Sc., M.Inst.C.E., M.Inst.M.E., F.G.S.
HIS MAJESTY'S CHIEF INSPECTOR OF MINES.
LATE PROFESSOR OF MINING IN THE UNIVERSITY OF BIRMINGHAM.
CERTIFICATED COLLIERY MANAGER, ETC.

LONGMANS, GREEN, AND CO.
39 PATERNOSTER ROW, LONDON
NEW YORK, BOMBAY, AND CALCUTTA
1908

All rights reserved

# PREFACE

THE present volume is the precursor of several others, which are to be brought out in successive order, the series constituting a complete work on modern practice in mining.

In view of the many text-books treating of the principles and practice of coal mining, the question may be asked, why add to the number, particularly as some of these so admirably fulfil the functions for which they were intended?

The answer to such a query would be that the work now being carried out follows lines quite distinct from those on which any existing treatise has been constructed, and is intended to meet wants which have frequently been brought before the writer's notice.

It is impossible to treat either exhaustively or adequately such an extensive subject as modern mining within the compass of a single volume, without the book assuming such bulky proportions as to render comfortable perusal impossible. Furthermore, mining, as now prosecuted, is made up of many branches, some of which are followed as professions apart from general mine engineering. Thus in the Colonies there is a class who may be called professional prospectors, whose province is the discovery, but not the development, of mineral deposits.

And both in the United Kingdom, the Colonies, America, and on the Continent, there are important companies having for their object the carrying out of boring operations for water, coal, mineral oil and gas, salts and metalliferous deposits. Again, there are individuals and companies, acting as contractors for the sinking and lining of shafts. Also contractors, who though neither owning nor managing coal-mines, engage to work and bring the coal to the surface; and again, the mechanical engineer, whose work lies entirely with the mine machinery, and is not greatly concerned with the methods of working coal or minerals. Unlike the mining engineer, none of these require for the study of their own particular department a complete treatise on mining.

Hence the design of the present scheme, in so far as it relates to coal mining, is to so divide up the subject, and give the latest information thereon, as to render each volume a comprehensive manual on a distinct department of coal mining. The subject-matter will, therefore, be apportioned as follows:—

Volume I. Coal: its Occurrence, Value, and Methods of Boring.
Volume II. The Sinking and Equipping of Colliery Shafts.
Volume III. Methods of Working Coal.
Volume IV. Ventilation of Coal Mines.
Volume V. Mechanical Engineering as applied to Collieries.

Other volumes, on metalliferous mining, are contemplated, as well as one on mine surveying, the latter the work of Mr. H. Briggs, B.Sc., A.R.S.M., and will be added to this series from time to time, so that the entire work will embrace a complete scheme of instruction in coal, ore, and stone mining, and yet allow of any one volume being obtained without committing its owner to the acquisition of any others of the series.

The writer's experience of mining, extending over twenty-four years, chiefly in a mine-managing capacity both at home and abroad, but latterly as a Professor of Mining, has impressed upon him the necessity, in a work of this kind, of a careful blending of theory with practice; and it will be observed that, wherever possible, theoretical precept has been supported by practical example. Out-of-date methods, whether as to mining or machinery, are avoided, and old practices only alluded to when warranted by the fact of their being still current. In some text-books an undue amount of space is devoted to obsolete methods and conditions, which, whatever may be their interest historically, are now of little or no practical value.

Formulæ when used will only be such as experience has shown to be of real value; and besides giving an indication of the reasoning by which these are arrived at, their use will be illustrated by practical examples.

Many of the figures illustrating the text have been, and will be, specially drawn for the volumes, but where recourse is had to existing illustrations they will in all cases be duly acknowledged.

It is not the writer's object to make the first three chapters of the present volume a substitute for the serious study of constructive geology, a knowledge of which constitutes a most important part of the equipment of the mining engineer, but rather to supplement such study, and give in a condensed and comprehensive form such geological and chemical facts relating to coal as are of interest from the miner's point of view. And if the perusal of the book leads to a wider and deeper investigation of geology and the other sciences allied to mining, an important part of the writer's object will have been achieved.

The manner of the occurrence of coal in different parts of the world, the chief characteristics, commercial value and relative importance of the various solid mineral fuels, the means of locating the deposits and estimating their extent and worth have been dealt with. Passing allusion has been made to some of the principal building stones, as being of importance to mining engineers in respect to the structures they have frequently to erect in order to win and work the coal deposits. The volume is intended indeed to form what may be termed the introductory chapters to a work on Coal Mining.

Since Mr. J. Clark Jefferson read his paper, entitled "History of Deep Boring or Earth Boring as practised on the Continent," before the Midland Institute of Mining, Civil, and Mechanical Engineers in 1877, no serious work on boring has appeared in the English language, although of late years great strides have been made in the art of drilling holes in the earth's crust; and by reason of the introduction of new and improved methods, the rate at which such work can be executed having vastly increased, whilst the cost has been correspondingly reduced. A *résumé*, therefore, of modern methods of boring is not out of place, and it is hoped may be of use to the prospector, the well-sinker, the mining engineer—whether he be a coal or metalliferous ore miner—and others interested in mining.

R. A. S. REDMAYNE.

# INDEX

AFRICA, South, borings in, 155
Agreement, form of boring, 160
Alsace-Lorraine, borings in, 130, 134
America (U.S.A.), lignite of, 14
American rope-drilling process, 82, 101, 102
Analysis, anthracite, 31
—— of cannel coal, 16
—— of coal gas, 17
—— of coals, method of conducting an, 32
—— of coking coals, 27
—— of gas coals, 25
—— of house coals, 28
—— of lignite, 14
—— of steam coal, 30
—— proximate, 26, 32
—— ultimate, 26
Anthracite, 2, 5, 11, 29, 31
Anticline, 49, 57
Arkansas (U.S.A.), lignite of, 14
Ash in coal, 29
*Asterophyllites*, 24
Austria-Hungary, coal output of, 6
Available supply of coal in British Isles, 11
Ayrshire coalfield, 8

BALKS, 64
Basalt, 76
Belgium, borings in, 131
—— coal output of, 6
Bituminous coal, 5, 17, 23, 24
Bogs, peat, rate of growth of, 3
Bohemia, coal in, 14
Bore-holes as salt-wells, 108
—— at Benzindenville, 158
—— at Bolderberg, 113
—— at Dieuslaken, 177
Bore-holes at Doncaster, 82
—— at Hartlepool, 81
—— at Kent coalfield, 81
—— at Lohse, 174
—— at Simmer and Jack mine, 174
—— at Turf Mines (Transvaal), 187, 188
—— cost of, 82, 108
—— deep, 80, 101, 145, 155, 158
—— deepest in the world, 81
—— deflection of, 173
—— diameters of, 81, 94, 109, 169
—— heat increment as measured in, 82
—— in Transvaal, 80, 158
—— in Victoria, 174
—— near Middlesbrough, 100
—— some important, 80
—— some uses of, 79
—— surveying of, 174
—— tubing of, 89, 108, 109, 169
Boring, 77
—— agreement, form of, 160
—— American system of, 82, 101, 102
—— by dredging, 120
—— Canadian system of, 101
—— chisel, 122
—— cost of, 82, 87, 108, 159, 162
—— Cyclone drill, 121, 167
—— deep, 101, 145, 155
—— depth at which it is feasible to bore with rigid rods, 90
—— described, 86
—— dry, 114
—— employment of water current in, 112
—— free-fall, 82, 91
—— Frich's apparatus, 135
—— Gaiski's system of, 96

Boring, general particulars relating to, 169
—— Hackenberg system, 135
—— head of tubing, 118
—— hydraulic, 82, 135
—— in a water sheet, 114
—— in Galicia, 101
—— injection of water, 119
—— journal, 171
—— Kind's free-fall, 91
—— Kleritj's system of, 96
—— Kolb's, 96
—— later developments in, 101
—— Mather & Platt's system of, 96
—— modern methods of, 112
—— old method of, 83
—— percussive, 82, 121
—— problems, 173
—— pumping pressure when, 116
—— Raky system of, 130
—— rate of, 87, 100, 108, 111, 113, 131, 134, 135, 140, 158, 163
—— Reinpreussen system of, 128
—— rods, 117
—— rods, junction of, to water-pipe, 118
—— rope, 82, 101, 102
—— rotary, 82, 140
—— Sonntag's system of, 96
—— systems of, 82
—— through clay and sand, 88
—— time occupied in drawing rods, 101
—— tools, 84, 85, 155
—— Verbunt's system of, 134
—— Vogt's system of, 134
—— Von Oeynhausen's arrangement, 91
—— with chilled steel shot, 82
—— with Davis Calyx drill, 163
—— with diamond drill. *See* diamond drill
—— with Dru's free-fall, 94
—— with Fauck's apparatus, 122
—— with flat rope, 97
—— with keystone core drill, 109
—— with rigid rods, 82, 83
—— with shot, 82, 163
Boring, with spring arrangement, 82
—— with steel crowns, 82
Bort or Borz, 156, 163
Boulder clay, 49
Boyd Nelson, reference to, 101
British coalfields, 7, 8, 10, 11
—— Empire, the coal output of, 6
Brora coalfield, 6
Brown coal, composition of, 2
Buhrbrauck, Martin, reference to, 130
Building stone, 74

*Calamites*, 23
Calculation of contents of coal seams, 36, 73
Calorific intensity of fuels, 36, 45
—— power of fuels, 36, 38
Calorimeters, 40
Canada, 6
Cannel coal, 2, 14, 15
—— coal, composition of, 2, 16
—— coal of Lancashire, 15
—— coal of Scotland, 15
Canobie coalfield, 8
Cape Colony, coal in, 7
Carbon, cost of, 163
Carboniferous limestone, 7
—— system, 6, 7
Carmarthenshire coalfield, 11
Casing of bore-holes, 89, 108, 109
*Caulopteris*, 21
Ceylon, graphite of, 2
Cheshire coalfield, 8, 11
China, coalfields of, 6
Chisel boring, 121
Clamps, safety, for holding bore-rods, 156
Clark, D. K., quoted, 37
—— Jefferson J., reference to, 96
Classification of coals, 4
—— of rocks, 48, 58
Clay, 74, 76
—— boring through. *See* Boring
Cleat of coal, 53
Cleavage, 53
Clinograph, the, 180

Clinometer, MacGeorge's, 181
Clyde basin, the, 8, 11
Coal, ash in, 29
—— available supply in British Isles, 11
—— bituminous, 5
—— cannel, 2
—— classification of, 4, 5
—— composition of, 2, 12
—— definition of, 1
—— distribution of, 5
—— dry, 5, 56
—— earthy, 2
—— gas, 14, 17
—— gaseous, 5, 14
—— in Natal, 7
—— manufacturing, 5, 28
—— measures, divisions of, 7
—— occurrence of, 5
—— of Cape Colony, 7
—— output, the, of British Empire, 6
—— output of the world, 5
—— reason for purity of, 21
—— search for, 77
—— semi-anthracitous, 5
—— semi-bituminous, 5
—— steam, 5, 10, 28, 30, 56
—— world's production of, 5
Coalbrookdale, 8, 11
Coalfields, British, 8
—— Cheshire, 8, 11
—— Cumberland, 8, 11
—— Denbighshire, 8
—— Derbyshire, 8, 11
—— Durham, 8, 9, 11
—— English, 8
—— Flintshire, 8
—— Forest of Dean, 8
—— Kent, 8
—— Lancashire, 8, 9, 11
—— Northumberland, 8, 9, 11
—— Nottinghamshire, 8, 11
—— of China, 6
—— of Coalbrookdale, 8, 11
—— of United States of America, 13
—— Russia, 6
—— Scottish, 8, 9, 11
—— Shropshire, 8, 11
Coalfields, Somersetshire, 8
—— South Wales, 8, 10, 11, 55, 56
—— Wyre Forest, 8
Coking coal, 25, 26, 27
Cologne, lignite from, 2
Common boring tools, 84, 85
Composition of British coals, 37
—— of typical coals, 2, 12
Conformity, 51
Contents of seams, 36, 73
Continuous recorder, Marriott's, 184
Contract boring, 160
Core protector, 151
Cost of boring, 82, 87, 108, 159, 162
Coupling arrangement in boring rods, 117
Cretaceous formation, coal in, 6
Crown, setting a, with diamonds, 153
Cumberland, coalfield of, 8, 11
Cyclone drill, 121

Davis Calyx drill, 163
Dax, brown coal from, 2
Deep bore-holes, 81
—— —— shafts of Belgium, 56
Definition of coal, 1
Deflection of bore-holes, 173
Denbighshire coalfield, 8
Density of peat, 3
Depth of bore-holes, 81, 90, 145
Derbyshire coalfield, 8, 11
Determination of the value of coals, 32
Diameters of bore-holes, 81
Diamond drill, the, 82, 140
—— —— American and British types, 142, 145
—— —— Continental use of, 142, 156
—— —— core-lifters, 144
—— —— core protection for, 151
—— —— cost of, 155
—— —— cost of boring by, 159, 162
—— —— counterweight arrangement for, 156
—— —— crown, 143
—— —— depth of borings by, 145, 155, 158

Diamond drill, hand-drilling with, 151
—— —— hydraulic feed for, 148
—— —— power necessary to drive, 82, 151, 158
—— —— rate of boring with, 158, 163
—— —— rate of driving, 142
—— —— screw or friction feed of, 149
—— —— setting a crown, 153
—— —— Sullivan types, 144, 146, 147, 150, 151
—— —— water current with, 142
Diamonds, cost of, 156, 163
—— cost of black, 163
—— when first used for boring, 141
Dip, apparent, 66
—— measurement of, 67, 68, 187
—— true, 69, 72
Distribution of coal, 5
Dredger, boring, 120
Dru's free-fall boring apparatus, 94
Dry boring, 114
—— coal, 5, 56
Duration of the coal supplies of Great Britain, 12
Durham coalfield, 8, 9, 11
Dyke, 56, 62

EARTHY coal, 2
Easington Colliery, boring at, 90
English coalfields, 8
Enlarging tool for bore-holes, 167
Evaporative power of coal, 37, 39

FALSE bedding, 51
Fat coals, 5
Fauck's boring apparatus, 122
Fault, ordinary, 58
—— reversed, 58
—— trough, 59
Faulting, 56, 58, 59
Fife coalfield, 8
Fireclay, 18
Flintshire, coalfield of, 8
Flushing bore-holes with water, 112, 113, 116
Folding, 55, 56
Forest of Dean coalfield, 8
Form of boring agreement, 160
Formations containing coal deposits, 6, 12
Fossil ferns, 21
—— trees, 19, 21
France, the coal output of, 6
Franco-Belgian coalfield, 55, 57
Frazer, Professor, classification of coals, 5
Free-fall arrangement in boring, 91
—— Dru's, 94
—— Fabian's, 96
Friction feed in boring, 149
Frieh's boring apparatus, 135

GALICIA, boring in, 101, 127
Gas, coal, 14, 16, 25
—— yield of, from various coals, 16
Gaseous coal, 5, 14
Geological disturbances, 55
—— formations, 48
Geology applied to coal mining, 48
German Empire, the coal output of, 6
Germany, peat in, 4
Glacial drift, 49
Glamorganshire coalfield, 10
Gloucestershire coalfield, 11
Goodwin, Austin, reference to, 81
Gothan's stratameter, 178
Graphite, composition of, 2
Granite, 74, 76
Green, Professor, quoted, 49, 50

HABETS, M., reference to, 131
Hackenberg system of boring, 135
Haddington, coalfield of, 8, 55
Hade, 56
Hartley coal, 2
Heating value of coals, 32, 36, 37, 38, 39, 40, 45
—— value of peat, 3
Heave, 59
House coal, 5, 26
Hull, Professor, reference to, 7
Hydraulic boring, 135
—— feed in boring, 148

Hydrofluoric acid, use of, in surveying bore-holes, 175

IGNEOUS rock, intrusions of, 62
Injection water in boring, 119
Intermittent recorder, Marriott's, 184
Inversion, 51, 52
Irish coalfields, 8
—— peat, 3
Iron smelting coal, 28

JAPAN, the coal output of, 6
Jennings, Hennen, reference to, 80
Jointing in rocks, 53
Journal, boring, 171
Jukes, J. Beete, quoted, 18, 67
Junction of boring-rods to water-pipe, 118

KENT coalfields, 8
Keystone core drill, the, 109
Kilbeggan peat, 3
Killingworth Colliery, 21
Koebrick, reference to, 178

LAMINATED rocks, 51
Lancashire, coalfield of, 8, 9, 11
Lebour, Professor G. A., reference to, 63
Leicestershire, coalfield of, 8, 11
Lenticular beds, 51
*Lepidodendron*, 24
Leschot, M., reference to, 141
Lesmahagow, coalfield of, 8
Lignite, composition of, 2, 12, 14
Limestone, 76
Lyell, Sir Charles, quoted, 22

M'FARLANE'S instrument for surveying bore-holes, 175
MacGeorge's instrument for surveying bore-holes, 174, 180, 181
Maps, geological, 78
Marriott's instruments for surveying bore-holes, 174, 183
Mather & Platt's system of boring, 96
Mathews, C. H., quoted, 107
Measurement of inclination of strata, 66
Meine's instrument for surveying bore-holes, 174, 179
Metric ton, value of, 5
Midland coalfield, 8, 11, 82
Midlothian, coalfield of, 8, 9, 55
Millstone grit, 7
Miocene, coal in, 12
Mississippi, formation of coal at, 122
Monmouthshire, coalfield of, 10
Mountain limestone, 7
Murchison, Sir R. I., reference to, 6

NAMUR coalfield, 55, 57
Natal coal, 7
*Neuropteris*, 21
Newcastle coal, composition of, 2
New Zealand, coal in, 13
Nip-out, 64, 66
Nolten's instrument for surveying bore-holes, 174
Nordhausen Boring Company, the, 135
North Stafford, coalfield of, 8, 9, 11, 55
Northumberland, coalfield of, 8, 9, 11
Nottingham, coalfield of, 8, 11

OBLIQUE Section Table, 69, 70
Occurrence of coal, 5
*Odontopteris*, 22
Oil wells, 81, 109, 127
—— wells in America, 81
Oolite formation, coal in, 6
Otto's instrument for surveying bore-holes, 174, 175
Output of coal for the United Kingdom, 11
Overlap fault, 58

PAGE, Professor D., quoted, 14
Peat, briquettes made of, 4
—— composition of, 2
—— manner of formation of, 3
—— uses of, 4
—— weight of, 3

*Pecopteris*, 21
Pembrokeshire, anthracite of, 11
Pennsylvania, bore-holes in, 79
Percussive boring, 82, 121
Peru, coal in, 7
Phosphorus in coal, 26
Piezometrical level, the, 115
Porosity of stone, 74
Portland stone, 75
Power necessary to drive drills, 82, 151, 158
Pressure of water in bore-rods, 116
Problem boring, 173
Producer gas, 4, 30
Prospecting, 77
Prussia, mining law in, 112
Pumping pressure when boring, 116

QUALITY of coal in different fields, 9
—— of coal. *See* Coal
Quantity of coal in Great Britain, 11

RAKY system of boring, 113, 130, 131
Rapid system of boring, 127
Rate of boring, 87, 100, 108, 111, 131, 135, 140, 158, 162
Recording results of borings, 176
Redwood, Sir Boverton, reference to, 89
Reinpreussen boring apparatus, 128
Renier, M. Armand, reference to, 89
Reversed fault, 58
Reynolds, C. B., reference to, 88
Rigid rods, boring with, 82, 90
Rods, boring, 117
Rolls, 64
Rope-drilling, 82, 101, 102
Roscoe, Sir H., quoted, 17
Rosenhain's calorimeter, 41
Rotary boring, 82, 140
Royal Commission on coal supplies, 11
Ruhr coalfield, borings in, 30
Russia, coal output of, 6
—— coalfields of, 6
Russian peat, 2

ST. GOTHARD tunnel, 141
Salt-wells, boring of, 108.
Samples taken from bore-holes, 167
Sand, boring through, 88
Scottish coalfields, the, 8, 9, 11
Search for coal, 77
Semi-anthracitous coal, 5
Semi-bituminous coal, 5
Sexton, A. H., quoted, 29
Shannon, peat from the, 2
Shot, drilling with, 165
Shropshire coalfield, the, 8, 11
*Sigillaria*, 20, 21
Simpson, J. B., reference to, 62, 64
Size of bore-holes, 169
Skye, coalfield in, 6
Slickensides, 58
Somersetshire coalfield, the, 8
South Africa, igneous dykes and overflows of, 63
South Stafford coalfield, 8, 11, 59
South Wales, 8, 10, 11, 55, 56
Spain, the coal output of, 6
Specific gravity of coal, 35
Sphagnum moss, 3
*Sphenopteris*, 21
Steam coal, 5, 10, 28, 30, 56
—— coal of South Wales, 11
Steel manufacture, coke used for, 26
*Stigmaria*, 18, 20
Stone building, 74
Stratameter, M'Farlane's, 177
—— MacGeorge's, 180
—— Marriott's, 183
—— Meine's, 179
—— Nolten's, 174
—— Otto's, 178
—— Vivian's, 178
Stratification, 49, 53, 187
Strike, 67, 187
Sullivan diamond drill, 144, 146, 147, 150, 151
Supply of coal in the British Isles, 18, 20
Surveying of bore-holes, 174
Swellies, 64
Swivel, water, 119, 121, 145
Syncline, 49, 57

Tertiary coal, 12, 14
Thickness of seam, determination of, 191
Thompson's calorimeter, 40
Throw of faults, 56
Tonnage, calculation of, in coal seam, 26, 73
Towneley Colliery, 64, 66
Transvaal, coal in the, 7
Trauzl & Co., 127, 128
Trepan or chisel, 121, 122
Triassic formation, coal in, 6
Tubing, head of, 118
—— of bore-holes, 89
Typical coals, composition of, 2

United States of North America, coal output of, 6
—— coalfields of, 13

Value of fuels, 32
Van Ertborn, Baron, reference to, 113
Variation in coal seams, 10
Verbunt's system of boring, 134
—— water swivel, 119
Vivian, reference to, 178
Vivian Diamond Boring Company, 82
Vogt system of boring, 134

Wallsend coal, 9
Warwickshire coalfield, 8, 11
Wash-outs, 64, 65
Water current used in boring, 112, 115, 116
—— sheets, boring in, 114
—— swivels, 119, 121, 145
Weight of peat, 3
Welsh steam coal, available supply of, 11
Westphalia, borings in, 131
Wigan, cannel coal from, 2
Wisconsin (U.S.A.), American rope-drilling in, 81
Wolski's boring apparatus, 135
Wood, composition of, 2
Wood, Nicholas, reference to, 21
Wooden boring rods, 101
World's, the, production of coal, 5
Wyre, Forest of, 8

Yorkshire, coalfield of, 8, 9, 11

END OF VOL. I.

Printed by Ballantyne, Hanson & Co.
Edinburgh & London

# CONTENTS

## CHAPTER I

PAGE
COAL: VARIETIES, COMPOSITION, AND OCCURRENCE . . . 1

## CHAPTER II

DETERMINATION OF THE VALUE OF FUELS . . . 32

## CHAPTER III

GEOLOGY APPLIED TO COAL-MINING . . . . 48

## CHAPTER IV

PROSPECTING AND BORING FOR COAL . . . . . . 77

## CHAPTER V

LATER DEVELOPMENTS IN BORING . . . . . . 101

## CHAPTER VI

SOME BORING PROBLEMS . . . . . . . . . . 173

# LIST OF ILLUSTRATIONS

FIG. PAGE

1. Map of the Coalfields of the United Kingdom . . . . . 10
2. Map of the Coalfields of the United States of America . . . . 13
3. *Stigmaria ficoides* . . . . . . . . . . . . . 18
4. (1) Fossil tree found at a depth of 288 feet from the surface . 19
   (2) Root or *stigmaria* of fossil tree . . . . . . . . 20
   (3) Face of flattened part at top . . . . . . . . 20
5. Fragment of *Sigillaria Graseri* . . . . . . . . 20
6. *Pecopteris elliptica* . . . . . . . . . . . 21
7. *Caulopteris primæva* . . . . . . . . . . . . 21
8. *Odontopteris Schlotheimii* . . . . . . . . . 22
9. *Calamites Cannæformis* . . . . . . . . . . 23
10. *Lepidodendron sternbergii* . . . . . . . . . 24
11. *Asterophyllites foliosus* . . . . . . . . . . 24
12. Platinum dish . . . . . . . . . . . . . 33
13. Hydrostatic balance . . . . . . . . . . . 35
14. Thompson's Calorimeter . . . . . . . . . . . 41
15. Rosenhain's Calorimeter . . . . . . . . . . 42
16. Coal Outcrop in New Zealand . . . . . . . . . 49
17. Plan and Section showing Stratification, Faulting, and Unconformity . . . . . . . . . . . . . . 51
18. Contorted Strata showing Inversion . . . . . . . 52
19. Unconformity accompanied by Change of Dip . . . . . 52
20. Stratification, Jointing, and Cleavage . . . . . . 53
21. Diagram illustrating Dip, Strike, Cleavage, Jointing, and Cross-jointing in a Bed of Slate . . . . . . . . . . 54
22. Section across the Franco-Belgian Coalfield . . . . . 57
23. Ordinary Fault . . . . . . . . . . . . . 58
24. Reversed Fault . . . . . . . . . . . . . 58
25. Trough Faults in the South Staffordshire Coalfield . . . 59

26, 27, 28, and 29. Diagrams explanatory of Faults and Heaves . . 60

30. Plan showing Faulting of a highly-inclined Bed . . . . 61

31 and 32. Diagrams explanatory of Schmidt's and Zimmerman's Rule for finding a lost part of a Vein or Seam . . . . . . 61

33, 34, and 35. Explanatory of the dying out of Faults . . . 62

36. Dyke or Vertical Intrusion of Trap Rock . . . . . . 63
37. Section at Great Bavington, Northumberland . . . . 64
38. Section across the Team Valley (Co. Durham) . . . . 65

FIG. PAGE
39. Nip-out . . . . 66
40. Diagram illustrating Dip and Strike . . . . 67
41. „ explanatory of Apparent and True Dip . . . . 68
42. „ illustrating manner of calculating Oblique Section Table 69
43, 44, and 45. Diagrams illustrating Observed and True Dip . 71, 72
46. Diagram illustrative of manner of calculating amount of True Dip 73
47. „ illustrating Computation of Contents of Inclined Seams. 73
48. Position of Bore-holes . . . . 79
49. Head-gear of Rigid Rod Boring Apparatus . . . . 84
50. Common Boring Tools . . . . 85
51. Boring Tools used at Easington Colliery Sinking . . . . 90
52. Kind's Boring Tool . . . . 92
53. Kind's Crown-borer and Core-extractor . . . . 93
54. Dru's Boring Apparatus . . . . 95
55 and 55A. Mather & Platt's Flat Rope Boring Apparatus . . 98
56. Mather & Platt's Boring Tool and Sludger . . . . 99
57. Rig of American Rope Drilling Apparatus . . . . 103
58. Some of the Tools used with the American Rope Drilling Apparatus 105
59. Keystone Core Drill . . . . 110
60. Percussive Drilling with Water-flushing . . . . 115
61, 62, 63, 64, 65, and 66. Types of Hollow Boring Rods . . . 117
67. Verbunt's Water Swivel . . . . 119
68. Boring by Dredging . . . . 120
69. Boring Chisels with Water Channels . . . . 121
70. Cyclone Percussive Bit . . . . 122
71. Fauck's Trepan . . . . 122
72, 73, and 74. Fauck's Hollow Trepan . . . . 123, 124
75 and 76. Fauck's Boring Apparatus . . . . 125, 127
77. The Trauzl Water Swivel . . . . 128
78. Plan of the Reinpreussen Boring Engine . . . . 129
79. Side Elevation of the Reinpreussen Boring Engine . . . 130
80. The Raky Boring Apparatus . . . . 132
81. Clamp used in Lowering Rods with Raky Drill . . . . 133
82. „ „ „ „ (Section) . . 133
83. Diagram Explanatory of the Action of the Hydraulic Boring Apparatus . . . . 136
84. The Frieh Hydraulic Boring Apparatus . . . . 139
85. Air-vessel of the Frieh Hydraulic Boring Apparatus . . . 139
86. Crown and Core Barrel of Diamond Drill . . . . 143
87. Diamond Drilling Apparatus . . . . 143
88. Types of Sullivan Core-lifters or Holders . . . . 144
89. Types of Water Swivels . . . . 145
90. Sullivan Diamond Core-drill with Screw Friction Feed . . . 146
91. „ „ „ Hydraulic Friction Feed . . 147
92. Sectional View of Single Cylinder Hydraulic Feed Mechanism . 148
93. Sullivan Hand-power Diamond Drill . . . . 150
94 „ Double Tube Core Barrel . . . . 152

FIG. PAGE
95. A Diamond Bit in the several stages of being "Set" . . . . 154
96. Safety Clamps . . . . . . . . . . . . 156
97. Counterweight Arrangement used when Boring with Diamond Drills in Germany . . . . . . . . . . 157
98. Topit and Holding Key . . . . . . . . . 158
99. Davis Calyx Drill . . . . . . . . . . . 164
100. Crown of Davis Calyx Drill showing Removable Teeth . . 165
101. Water Swivel and Shot Feed of Cyclone Drill . . . . 166
102. Spiral Shot Bit of Cyclone Drill . . . . . . . 167
103. Section of Boring Arrangement of Cyclone Drill . . . . 168
104. Enlarging Tool for taking Samples from Seams bored through . 168
105. Diagram illustrative of Declination of Bore-holes . . . 173
106. „ explanatory of the Action of Nolten's Stratameter . 175
107 and 108. Nolten's Stratameter . . . . . . . . 176
109. Otto's Stratameter . . . . . . . . . . 178
110. Meine's Stratameter . . . . . . . . . . 180
111. MacGeorge's Clinostat . . . . . . . . . . 181
112. „ „ in its Protecting Tube . . . . 181
113. „ Clinometer . . . . . . . . . 182
114 and 115. Marriott's Continuous Recorder . . . . . . 184
116. Marriott's Intermittent Recorder . . . . . . . 186
117. Improved Compass Attachment for the Intermittent Recorder . 187
118. Plan and Section of East Bore-hole sunk by the Turf Mines, Ltd., Transvaal . . . . . . . . . . . . . 188
119. Diagram showing Position and Level of Bore-holes put down to Determine the Dip and Thickness of a Coal-seam . . . 187
120. Diagram illustrating Calculation for finding the Direction and Amount of Dip . . . . . . . . . . . . 189
121. Diagram illustrating Calculation of Course of Dip . . . 190
122 and 123. Diagrams illustrating Calculation of True Thickness of a Seam . . . . . . . . . . . . . 191

# LIST OF TABLES

TABLE — PAGE

I. Composition of some Typical Fuels . . . . . . . . 2
II. Classification of Coals . . . . . . . . . . . 5
III. Classes of Coal . . . . . . . . . . . . . 5
IV. Composition of Lignite . . . . . . . . . . 14
V. Yield of Gas per Ton of Cannel Coal . . . . . . 16
VI. Comparative Statement as to Value of Cannel and Ordinary Coal Gas . . . . . . . . . . . . . 17
VII. Gas Coals . . . . . . . . . . . . . . 25
VIII. Coking Coals . . . . . . . . . . . . . 27
IX. House Coal . . . . . . . . . . . . . 28
X. Composition of the Ash in Coal . . . . . . . . 29
XI. Composition of Steam Coals . . . . . . . . . 30
XII. Anthracite . . . . . . . . . . . . . . 31
XIII. Average Composition of British Coals, with their Weight, Bulk, Heat of Combustion, and Evaporative Power . . . . 37
XIV. Geological Formations of Great Britain . . . *To face* 49
XV. General Classification of Derivative Rocks . . . . . 50
XVI. Nearest Degree of Dip, or each 1 in 100, answering to each Inch in a Yard . . . . . . . . . . . . 67
XVII. Oblique Section Table . . . . . . . . . . 70
XVIII. Rate and Cost of Boring by the Raky System . . . . 131
XIX. Boring Journal . . . . . . . . . . . . 171

# MODERN PRACTICE IN MINING

## CHAPTER I

### COAL: VARIETIES, COMPOSITION, AND OCCURRENCE

BEFORE entering upon a study of the principles of coal-mining, it is expedient that one should have a fairly comprehensive knowledge of the substance to be mined. The chemical composition and physical characteristics of fossil fuel, as well as the manner of its occurrence, are matters of moment to all those connected with industrial enterprise, as well as to mining engineers.

**What is Coal?**—Under the head of Coal may be comprehended all those solid fuels which are contained in the earth's crust, varying greatly in point of age and also as to chemical composition; the figures given in Table I., on the next page, show how great this variation may be.

It will be observed from this table that, generally speaking, the older the geological formation in which it occurs the higher is the percentage of carbon and the less the amount of volatile constituents in the fuel. Woody fibre and peat have been introduced into the table to further emphasise this peculiarity. The difference in the composition of the fuels is due, however, more to the extent of the metamorphic action to which they have been subjected than to age *per se*. This feature might

TABLE I.—*Composition of some Typical Fuels.*

| Name of Fuel. | Percentage Composition. | | |
|---|---|---|---|
| | Carbon. | Hydrogen. | Oxygen and Nitrogen. |
| 1. Wood from the Shannon . . | 52·65 | 5·25 | 42·10 |
| 2. Peat from the Shannon . . | 60·44 | 5·96 | 33·60 |
| 3. Lignite from Cologne . . . | 66·96 | 5·27 | 27·76 |
| 4. Earthy brown-coal from Dax | 74·20 | 5·89 | 19·90 |
| 5. Cannel coal from Wigan . . | 85·81 | 5·85 | 8·34 |
| 6. Newcastle (Hartley) coal . | 88·42 | 5·61 | 5·97 |
| 7. Anthracite from Wales . . | 92·85 | 3·96 | 3·19 |

have been further illustrated by including "graphite" and the "diamond." [1]

**Peat.**—Peat is frequently, and erroneously, regarded as coal "in the making," whereas *true* coal, as will be presently shown, owes its origin neither to peat bogs nor yet to the forest tree, but to forests of cryptogamic plants. Although peat, therefore, properly speaking, is not coal, nor will in the process of time become such, yet so considerable are the potentialities of these deposits as possible fuel supplies in the future, and so much attention has of late been directed towards them,[2] that some notice of the subject in these pages will not be considered out of place.

---

[1] Graphite (plumbago, blacklead) consists of carbon with from 0·3 to 0·5 per cent. of impurity, usually in the form of lime, iron, or alumina; but some graphites contain a much higher percentage of impurity and are commercially valueless. The following is an analysis of a typical Ceylon graphite:—

| | Per Cent. |
|---|---|
| Carbon . . . . . . . . . | 99·28 |
| Volatile matter . . . . . . | 0·301 |
| Ash . . . . . . . . . . . | 0·415 |

The diamond is practically pure carbon.

[2] In Russia the peat industry is supervised by a special office under the Ministry of Agriculture and Domains (*Bureau de l'Industrie des Toubes*). And an official map was shown at the Paris Exhibition giving information of about 113 "turbaries," occupying about an area of 398 square miles.

The formation of peat is commonly due to the remains of different kinds of mosses, in Great Britain chiefly of the genus *sphagnum*, but in some countries it owes its origin to other plants.

There are several million acres of peat in Great Britain alone, varying from 5 to 30 feet in thickness, and in North America from 800 to 1000 square miles of a thickness of from 5 to 25 feet, besides vast areas in Europe and Northern Asia.

The rate of growth of peat bogs is variable, and our knowledge respecting the same is somewhat indefinite; but it has been estimated that some extensive peat bogs in Great Britain have increased in vertical thickness by 3 to 5 feet since the date of the Roman invasion.

The density of peat is often given as varying between 0·25 and 1·4; but for the purposes of estimating the available tonnage in any given area the figures given by Sir Robert Kane may be used, viz. :—

1 cubic yard of light (domestic) peat weighs 500 lbs.
1 cubic yard of good peat weighs 900 lbs.
1 cubic yard of the densest peat weighs 1100 lbs.

The fact of peat containing in its natural condition so much water, frequently as high as 90 per cent. in mountain peat, has prevented its more extensive use both as fuel and for other purposes. The cost of drying and compressing it acts as a deterrent.

The composition of the best Irish (Kilbeggan) dried peat may be given as—

| | Per Cent. |
|---|---|
| Carbon | 61·04 |
| Hydrogen | 6·07 |
| Oxygen<br>Nitrogen | 30·46 |
| Ash | 1·83 |
| | 99·40 |

representing a heating value of about 5200 calories, or 9160 B.T.U., which compares favourably with some coals.

In Germany, peat is being successfully used in the generation of producer-gas, the gases made from peat being unusually clean and almost free from arsenides and sulphur. The chief use for peat in the future would seem, however, to lie in the direction of the manufacture therefrom of carbonised briquettes, though the huge masses of raw material that have to be handled in order to obtain a comparatively small quantity of serviceable fuel renders most, if not all, existing processes unprofitable. Efforts are, however, being made in several countries to put this manufacture on a commercial footing, and doubtless a method will eventually be evolved of profitably utilising these vast stores of carbonaceous wealth.

**The Classification of Coals.**—Coal may be classed according to the relative proportion of volatile hydrocarbons to fixed carbon in the total carbonaceous contents. Thus, taking a sample of Natal coal dried at about 212° F., the following analysis is given:—

| | Per Cent. | |
|---|---|---|
| Volatile hydrocarbons | 16·63 | 87·16 |
| Fixed carbon | 70·53 | |
| Sulphur | 4·18 | |
| Ash | 8·66 | |
| | 100·00 | |

From the low percentage of volatile hydrocarbons it might be supposed that, adopting the classification given below, this was a semi-bituminous coal; but the true relative values of volatile hydrocarbons to fixed carbon are not as 16·63 to 70·53, but as 19 to 81,[1] which would bring it under the class of bituminous coal.

The author has found it advisable to adopt the following broad classification (of coals), which he founds on a wide experience of a great variety of coal, British and foreign :—

---

[1] For 87·16 : 100 :: 16·63 : 19.

TABLE II.—*Classification of Coals.*

| Class of Coal. | Relative Percentage. | |
|---|---|---|
| | Fixed Carbon. | Volatile Hydrocarbon. |
| *Gaseous*, highly bituminous[1] or "fat" coals . . . . . . . . | 50 to 60 | 50 to 40 |
| *Bituminous*, further divisible into "house," "manufacturing," second class "gas," and second class "steam" coals . . | 68 to 82 | 40 to 18 |
| *Semi-bituminous*, steam or "dry" coal . | 82 to 88 | 18 to 12 |
| *Anthracitic*, coals ranging between semi-anthracitic and pure anthracite . . | 88 to 96 | 12 to 4 |

Numerous other divisions have been suggested; that of Professor Frazer is worthy of notice, and, as being frequently adopted, is given below :—

TABLE III.

| Classes of Coal. | | Ratio $\frac{C.}{Vol.\ H.C.}$ : 1. | | |
|---|---|---|---|---|
| Bituminous . . . . . . | from | 5 : 1 | to | 10 : 1 |
| Semi-bituminous . . . . | „ | 9 : 1 | „ | 5 : 1 |
| Semi-anthracites . . . . | „ | 12 : 1 | „ | 8 : 1 |
| Hard dry anthracites . . . | „ | 5 : 1 | „ | 10 : 1 |

## Distribution and Occurrence of Coal

**The World's Production.**—Coal, of all substances mined, is the most widely distributed, and is produced in larger quantities than any other commodity. The world's production of coal during the year 1905 was no less than 941,015,007 metric tons,[2] the value of which was estimated at more than £305,000,000 sterling, the chief producers being—

---

[1] Bituminous coal is in reality a misnomer, a bituminous coal containing no actual bitumen, but its use is sanctioned by long-standing custom.

[2] A metric ton (tonneau, millier, or tonne) is equivalent to 2204·6 lbs. av.

| | | Metric Tons. |
|---|---|---|
| The United States of North America | contributing | 356,454,088 |
| The British Empire (of which Great Britain and Ireland contributed £239,918,239) | „ | 269,929,379 |
| The German Empire | „ | 173,810,669 |
| Austria-Hungary | „ | 42,454,004 |
| France | „ | 35,927,704 |
| Belgium | „ | 21,775,280 |
| Russia | „ | 19,628,008 |
| Japan | „ | 11,542,041 |
| Spain | „ | 3,371,919 |

**Formations containing Coal Deposits.**—Though by far the greater stores of coal, and those which are best in quality, are contained in the Carboniferous system, coal is by no means limited to that geological horizon. Eliminating lignite, which exists chiefly in the Tertiary deposits, coal has been found as low down in the geological scale as the Silurian system. The coalfields of Russia were considered by Sir R. I. Murchison to belong to the Lower Carboniferous period,[1] but others are of the opinion that they are of Old Red Sandstone origin. The immense and remarkable field in the provinces of Hoonan and Shansi (China)—the latter province enormously rich in coal and iron, being, perhaps, even more extensive and richer than the great Pennsylvanian coalfield of North America—is, like the Indian fields, of later origin than Carboniferous times. In Lower Austria coal is mined from seams in the Triassic, Liassic, and Upper Cretaceous formations. The small coalfield at Brora, near Dornoch in Sutherlandshire, is of Lower Oolitic age, as is also a small field in Skye. In Canada, the coal of the Pacific Coast, generally bituminous, is of Cretaceous age. The thick seams of excellent coal in the vicinity of the Crow's

---

[1] *Russia and the Ural Mountains*, vol. i. p. 69.

Nest Pass (Canada), which are now being extensively exploited, belong to the Cretaceous period. True coal and anthracite are found in the Cretaceous and Jurassic rocks of Peru, whilst the coalfields of Cape Colony, the Transvaal, and Natal are, in all probability, of Triassic age and subaqueous origin.

**The Carboniferous System in Great Britain.**[1] —The largest number of fields of bituminous coal and anthracite belong, as has been said, to the Carboniferous system—the great majority of the British coalfields, for instance. Broadly speaking, the Carboniferous system of the United Kingdom can be divided into three subdivisions.

| | |
|---|---|
| 1. Coal Measures. | Strata of shale and sandstone, with occasional seams of coal, fireclay, and, in some fields, ironstone. Is further divisible in some of the fields into Upper, Middle, and Lower Coal Measures. Total thickness varying from 600 to 10,000 feet. |
| 2. Millstone Grit. | Usually a coarse quartzose sandstone, which has in some parts been used for millstones, with beds of shale, but rarely of coal. Sometimes exceeds 600 feet in thickness, and is known as "Farewell Rock." Absent in some coalfields. |
| 3. Mountain or Carboniferous Limestone. | Limestones of varying thickness, with some calcareous shales, sandstones, and grits. In part of Northumberland containing several workable seams of coal. Total thickness very variable, being sometimes more than 2000 feet. Entirely absent in several of the coalfields, as, for instance, in Staffordshire and Warwickshire, where the coal measures repose directly on a Silurian floor. |

The extent and relative positions of the British coalfields are shown on the accompanying map, Fig. 1, in large measure a copy of that submitted by Professor Hull to the first (Argyll) Royal Coal Commission, and published by them in their Report of 1871.

---

[1] For a synopsis of what is known concerning the geological conditions, extent, and available resources of the coalfields of the United Kingdom, the reader cannot do better than refer to *The Coalfields of Great Britain*, by Edward Hull, M.A., F.R.S., and the *Reports on the Available Coal Resources of the Various Districts*, by the Royal Commission on Coal Supplies, 1905.

**The British Coalfields.**—Professor Hull has divided the coalfields into groups, and his arrangement is, with some additions, here reproduced as being the most convenient.

### I. ENGLISH COALFIELDS

*Midland Group.*—1. North Staffordshire; 2. South Staffordshire; 3. Leicestershire; 4. Warwickshire.

*North Midland Group.*—1. Yorkshire; 2. Derbyshire and Nottinghamshire.

*Great Northern Group.*—1. Durham and Northumberland; 2. Cumberland.

*North-Western Group.*—1. Lancashire and East Cheshire; 2. Coalbrookdale (or Shropshire); 3. Forest of Wyre.

*Western Group.*—1. Bristol and Somersetshire; 2. Forest of Dean.

*Southern Group.*[1]—The Kent coalfield.

### II. WELSH COALFIELDS

1. South Wales Field; 2. Denbighshire; 3. Flintshire.

### III. SCOTTISH COALFIELDS

1. The Clyde Basin; 2. Midlothian; 3. Haddingtonshire; 4. Fifeshire; 5. Ayrshire; 6. Lesmahagow; 7. Canobie.

### IV. IRISH COALFIELDS

1. Northern Group; 2. Southern Group.

It is probable that, in the majority of cases, the coalfields of Great Britain are geologically of the same age, and at one time constituted one contiguous tract. Through the agency of past denudation they now form detached areas. As to the nature of the coal considerable diversity exists, and this variation, coupled with the abundance of the different classes, has conduced more than anything else to the establishment of British commercial greatness.

---

[1] This coalfield, the positive existence of which has been proved by borings and sinkings since the first edition of Hull's work, was not included in his grouping of the fields, nor is it indicated on his map.

Coal-mining, until comparatively recent times, was carried on to a greater extent in some fields than in others, that is to say, the coal was easier got, of better quality, or nearer to centres of consumption or the sea-board than in the less worked fields. Gradually, however, the other fields began to be developed, so that at the present time, whilst some of the coal-mining districts may be regarded as progressive areas, that is to say, have not yet attained to the zenith of their productive development, others are either stationary or retrogressive. And though some of these latter may show increased annual production, this is due rather to augmentation of output from existing collieries than to any further extension of development.

**Quality of the Coal in the different Fields.**—Allusion has been made above to the great variety of coal mined in the United Kingdom; this variation in quality is found to exist also within individual fields. For instance, good coking coal is mined near the banks of the river Tyne, west of Newcastle; yet close to Newcastle itself the celebrated Wallsend household coal was produced. What is said to be the finest coke in Europe is made from coal worked in the western and south-western portion of the Durham part of the Northern field, yet good gas and first-class house coals are raised from the collieries in the central and eastern districts of Durham. The chief steam-coal producing districts are South Wales, Northumberland, some of the Scottish fields, and to some extent, also, Lancashire, North Staffordshire, and York-

*shire.* The Midland fields, however, yield principally house, manufacturing, and iron-smelting coals, as well as coals of gas and coking quality.

*The quality of British steam-coal, especially that* derived from the central part of Glamorganshire in the South Wales coalfield, is regarded as superior to all other steam-coal at present in the markets of the world.

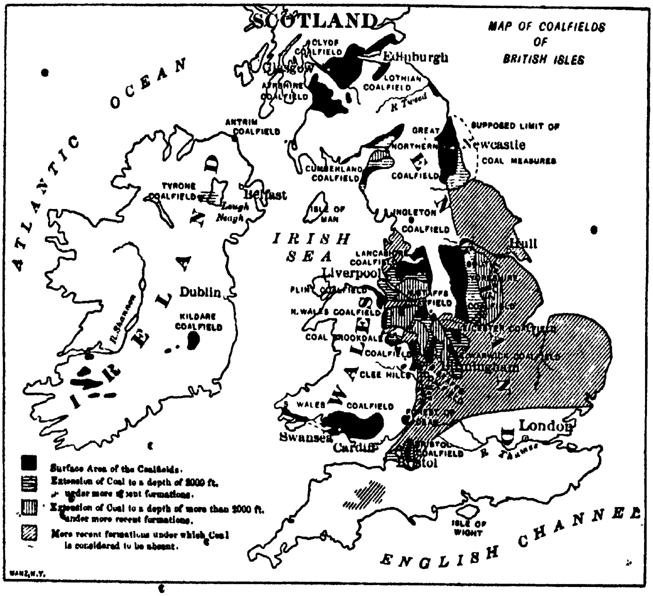


FIG. 1.—Map of the Coalfields of the United Kingdom.

The South Wales coalfield, with the exception of the Clyde basin, is the largest in the United Kingdom—taking into consideration only the exposed portion of the latter field (see Fig. 1). It is also remarkable for the great variety it presents in the character of its seams. In Monmouthshire these are bituminous, but become less so towards the south-west, until in Mid-Glamorgan they constitute the smokeless steam-coal, used in the Royal and some other navies.[1] Towards the west (Pembrokeshire and Carmarthenshire) the seams pass into anthracite.

*As illustrating the relative importance of the several* fields, the approximate annual production therefrom in millions of tons (based on the returns for 1906) is given below:—

| | | Million Tons. | |
|---|---|---|---|
| Scotland | Fifeshire | 7¾ | 38 |
| | Lothian, Clyde, and other coalfields | 25¾ | |
| | Ayrshire | 4½ | |
| England | Great Northern coalfield | 52 | 174½ |
| | Cumberland | 2¼ | |
| | Chester | ½ | |
| | Midland: Yorkshire<br>Derbyshire<br>Nottingham<br>Leicestershire | 61½ | |
| | Lancashire | 24¾ | |
| | N. and S. Staffordshire | 13½ | |
| | Warwickshire | 4 | |
| | Shropshire | ¾ | |
| | Worcestershire | ½ | |
| | Gloucestershire | ½ | |
| | Somerset | 1 | |
| | Monmouthshire | 12¼ | |
| Wales | South | 46¼ | 50¼ |
| | North | 4 | |
| Ireland | | 1/10 | 1/10 |

**Available Supply of Coal in the British Fields.**—The final Report of the Royal Commission of Coal Supplies was issued in January 1905, and from it are gleaned the following particulars:—

The estimated available quantity of coal in the proved coalfields of the United Kingdom up to a depth of 5000 feet from the surface is estimated at 100,914,668,167 tons; and of this amount 79·3 per cent. is contained in seams 2 feet thick and upwards, and 91·6 per cent. in seams of 18 inches and upwards. The resources in the proved fields below 4000 feet are estimated at 5,239,433,980 tons, and in unproved fields at depths less than 4000 feet at 39,483,000,000 tons.

---

[1] The available resources of first-class Welsh steam-coal were stated by the recent Royal Commission on Coal Supplies to be amply sufficient to supply the British Navy for many years to come, being estimated at 3937 million tons, whilst the present annual output is 18 million tons.

As to the duration of the coalfields, the Commission hesitated to pronounce definitely. Over the previous thirty years the average increase in output has been at the rate of 2½ per cent. per annum, but the Commission considered it highly improbable that the then rate of increase of the output would be long continued, owing to physical considerations.

The extent and relative positions of the great coalfields of the United States of America are shown on Fig. 2, which is interesting as a comparison with British resources.

**Varieties of Coal.**—(1) *Lignite or Brown-Coal.* Differs from ordinary coal in that its formation is the result of partially mineralised wood. Frequently, indeed, it has the appearance of charred wood, and retains much of its fibrous structure, but sometimes it is pitch-like, showing no vegetable structure whatever.

Lignite is of Tertiary age. In Britain deposits are found in the Lower Miocene formation at Bovey Tracey in Devonshire, the lignite being associated with beds of sand and clay, surrounded by the granite and other rocks of Dartmoor, and forming a plain ten miles long by two and a half broad. The vegetable matter from which these lignites were made was largely derived from various species of *sequoia*, especially the *Wellingtonia.* The deposits are very impure, and have not been worked since the year 1894, for which year the output amounted to only 334 tons.

Very large quantities[1] of lignite are produced in other countries. More than a quarter of the coal output of the German Empire, or 52 million (metric) tons, is brown-coal. France raises three-quarters of a million (metric) tons, and more than one-third of the total New Zealand coal output (or about 600,000 metric tons per annum) is brown-coal, most of which is obtained in the southern district of Middle Island, much of it being worked "open-cast," as shown in Fig. 16, p. 49.

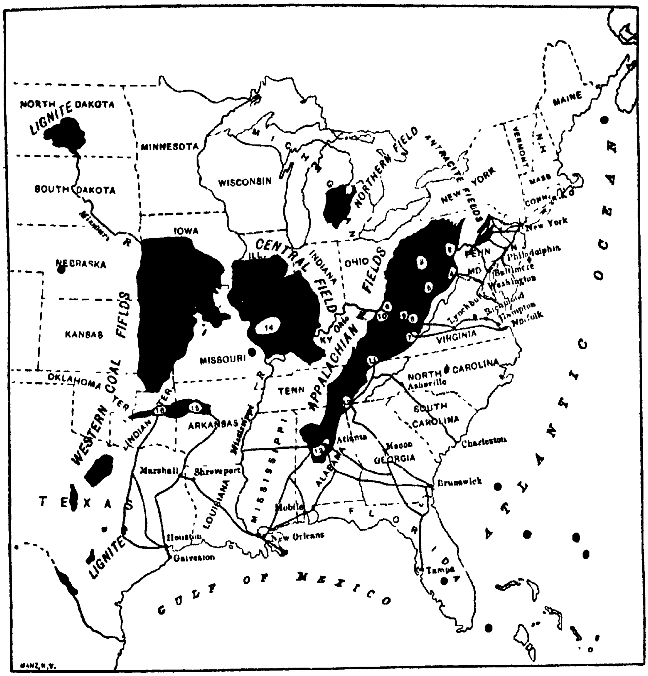


FIG. 2.—Map of the Coalfields of the United States of America.

---

[1] The figures given are those for the year 1905.

In the Teplitz basin in Bohemia the seams often reach a thickness of 98½ feet in the Lower Miocene; and in the Upper Oligocene, in the same basin, there are seams 3 feet in thickness. In Styria there are seams of from 50 to 100 feet thick, and in one place a seam nearly 200 feet thick in the Miocene formation. Austria contributes over 22 million (metric) tons of lignite per annum to her coal production. In Spain the lignite is entirely confined to the beds of the Cretaceous period.

The following table affords important information as to the value of some of the better known lignites:[1]—

TABLE IV.—*Composition of Lignite.*

| Country. | Percentage Composition. | | | | | Ashes. | Specific Gravity. |
|---|---|---|---|---|---|---|---|
| | Carbon. | Hydrogen. | Oxygen. | Nitrogen. | Waste. | | |
| Tasmania | 50·90 | 4·66 | 15·99 | 1·08 | 13·43 | 4·64 | Varying from 0·6 to 1·5 |
| France | 70·49 | 5·59 | 18·00 | 0·93 | ... | 4·99 | |
| " | 63·88 | 4·58 | 17·10 | 1·00 | ... | 13·43 | |
| Switzerland | 70·02 | 5·20 | 20·50 | 1·27 | ... | 3·01 | |
| Greece | 61·20 | 5·00 | 23·50 | 1·28 | ... | 9·02 | |
| Bohemia | 73·79 | 7·46 | 12·79 | 1·00 | ... | 4·96 | |
| Germany | 70·12 | 3·19 | 7·59 | 1·00 | 3·63 | 15·47 | |
| " | 60·83 | 4·36 | 23·50 | 1·14 | 9·07 | 2·43 | |
| Persia | 63·55 | 6·68 | 26·00 | 1·93 | ... | 3·05 | |
| Siberia | 47·46 | 4·50 | 32 09 | 1·03 | ... | 14·95 | |

The more pitch-like variety of lignite, such, for instance, as is found in Arkansas (U.S.A.), is frequently unfit for fuel, as it softens at a low temperature.

(2) *Cannel Coal and Coal Gas.*—Cannel coal, when once ignited, continues to burn with a steady clear flame,

---

[1] See *Economic Geology*, by D. Page, LL.D., F.G.S., p. 161.

emitting much smoke, until consumed, and it is from these properties that it derives its name.[1]

It is usually smooth, and of a dull black colour, though some cannels are possessed of a lustrous appearance. It does not soil the fingers when handled, and on being broken across the natural partings presents a conchoidal or shell-like fracture; in fact, it has much the semblance of pitch, and though undoubtedly having a plant origin, as shown by the impressions of *stigmaria* sometimes present, all indications of vegetable fibrous structure have entirely disappeared. When scratched it shows a brown streak. From the manner of its occurrence, it being found in basin-shaped formations, its association with shales (arenaceous and argillaceous), and the absence of true under-clay, cannel coal is evidently a "drift" deposit. It sometimes grades into an impure coal or shale, and frequently forms a distinct layer above or in a coal-seam, as, for instance, in the Moss seam at the Homer pit of the Stafford Coal and Iron Company, which seam is there found at a depth of 851 yards from the surface, having the following section:—

| | Ft. | In. |
|---|---|---|
| Roof—dark bind. | | |
| Cannel coal (inferior) . . . . . . | 1 | 6 |
| Coal (good) . . . . . . . . . | 0 | 6 |
| Cannel (inferior) . . . . . . . | 0 | 6 |
| Coal (good) . . . . . . . . . | 6 | 4 |
| Floor—fireclay. | | |

The cannel in the above seam, though inferior as a house coal, is suitable for generating gas.

---

[1] In Lancashire this coal was actually used by the poor in the seventeenth century as a substitute for candles. "This neighbourhood (*i.e.* Haigh near Wigan) abounds with that fine species of coal called cannal or candle. It is curious and valuable, and besides yielding a clear flame when burnt, and therefore used by the poor as candles, is wrought into candlesticks, plates, boxes, &c., and takes a fine polish like marble" (Camden's *Britannia*, Gough's ed., vol. iii. p. 390). It is also called "Parrot" coal in Scotland because of the crackling noise it makes when burning.

A sample of Newbattle (Scotch) cannel coal is thus described by Mr. G. R. Hislop, F.C.S.,[1] &c.: "The coal inclines to brownish-black, possesses considerable lustre, and yellowish-brown streak; fracture generally inclines to slaty, but in part irregular to curly, with impressions of stigmaria; cross fracture inclines to conchoidal, but partly angular to curly, with deposits of ferric bi-sulphide and calcium carbonate in the natural partings. Very cohesive and compact; on the fire it partly and very slightly intumesces but does not agglomerate; colour of ash, brownish-white; thickness of seam, 8 inches; mean specific gravity, 1·175; weight of a cubic foot, 73·43 lbs."

| | | Per Cent. |
|---|---|---|
| Volatile matters (containing 0·56 of sulphur) | | 50·23 |
| Coke, consisting of— | | |
| Carbon | 44·06 | |
| Sulphur | 0·24 | |
| Ash | 4·33 | |
| | | 48·63 |
| Moisture | | 1·14 |
| | | 100·00 |

The relative yields of gas per ton of coal for some typical cannels are given below.

TABLE V.—*Yield of Gas per Ton of Cannel Coal at* 600° F. *and* 30-*in. Bar.*

| Country. | Name of Coal. | Yield of Gas per Ton of Coal in Cubic Feet. | Illuminating Power of the Gas in Standard Candles. | Remarks. |
|---|---|---|---|---|
| Scotland | Newbattle cannel coal | 13,720 | 35·24 | Very rich |
| | Auchlochan Lesmahagow six feet cannel coal | 12,716 | 32·43 | Rich |
| Lancashire | Collins green cannel | 13,440 | 35·78 | Very rich |
| | Colborne gas coal | 12,620 | 20·42 | |

---

[1] ***Analyses of British Coals and Coke*, by A. Greenwell and J. V. Elsden, p. 267.**

*Coal Gas.*—Cannel coal is used entirely for the generation of gas, and, on account of the high illuminating power of the gas distilled from it, cannel is frequently mixed with poorer coals. The value of cannel gas as an illuminant, as compared with that produced from other coals, is due to the higher percentage it contains of heavy hydrocarbons. In ordinary gas the diluting and non-luminous burning gases are hydrogen, carbonic oxide, sulphuretted hydrogen, and the vapour of carbon disulphide, and in the purifying processes the object is to withdraw these gases. The comparative merits of cannel and ordinary gas coal for illuminating purposes are shown in Table VI. (see Sir H. Roscoe's "Elementary Chemistry").

TABLE VI.—*A Comparative Statement as to Value of Cannel and Ordinary Coal Gas.*

| | Illuminating Power in Candles per 50 Cubic Feet. | Composition in 100 Volumes. | | | | | |
|---|---|---|---|---|---|---|---|
| | | Hydrogen (H). | Marsh Gas ($CH_4$). | Heavy Hydrocarbons ($CH_2$). | Equal to Defiant Gas ($C_2H_4$). | Carbonic Oxide (CO). | Nitrogen, Oxygen, and Carbonic Acid (O, N, and $CO_2$). |
| Cannel gas . | 34·4 | 25·82 | 51·20 | 13·06 | (22·08) | 7·85 | 2·07 |
| Coal gas . . | 13·0 | 47·60 | 41·43 | 3·05 | (6·97) | 7·82 | ... |

**Bituminous Coal: Its Formation, Structure, and Quality.**—The nature of lignite and cannel coals has been described, but the mode of origin of so-called bituminous or common coal as it occurs in our coalfields is a more complex matter. It has been stated that the coal measures comprise alterations of sandstones, shales, fireclays, and coal, the sandstones having a predominating thickness. Both the sandstones and shales appear to have been deposited in, comparatively speaking, shallow water, and during a slow, and probably intermittent, depression of the surface, these areas of shallow water being fed by rivers (as is exemplified in the case of the Mississippi), bringing down continuous supplies of sediment, mud, and sand; and just as we see at the present day in the deltas of great rivers in warm climates, this area was occasionally covered with vast forests, though the growth was of a very different kind, consisting of gigantic club mosses. And, like the deltas alluded to, these great tracts were occasionally—long periods intervening—submerged beneath the fresh or salt water by the land sinking a few feet.

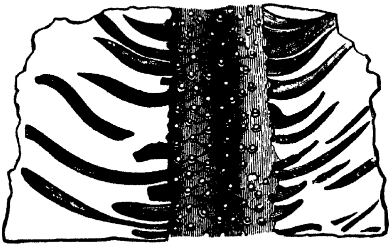


FIG. 3.—*Stigmaria ficoides.* (One-fourth natural size.)
(Nicholson's *Manual of Palæontology.* W. Blackwood & Son.)

Immediately underlying nearly every coal-seam in the United Kingdom is a bed of arenaceous shale, termed an underclay, varying from a few inches to several feet thick.[1] It is these beds which, in their purer state, are frequently mined for fireclay. Mr. J. Beete Jukes,[2] in describing the fireclay in Staffordshire, defines these fireclays generally as "a clay having a certain proportion of silica in its composition, and therefore capable of making firebricks. It is generally unctuous to the touch as soon as it is got, which the other argillaceous beds rarely are. It is commonly a brownish-grey, sometimes nearly black, but

---

[1] Some of the fireclays are over 10 feet thick, notably in South Wales and South Staffordshire.

[2] *On the Geology of the South Staffordshire Coalfield*, by J. Beete Jukes, M.A., F.C.S., &c.; *Records of the School of Mines*, vol. i. part ii. p. 162.

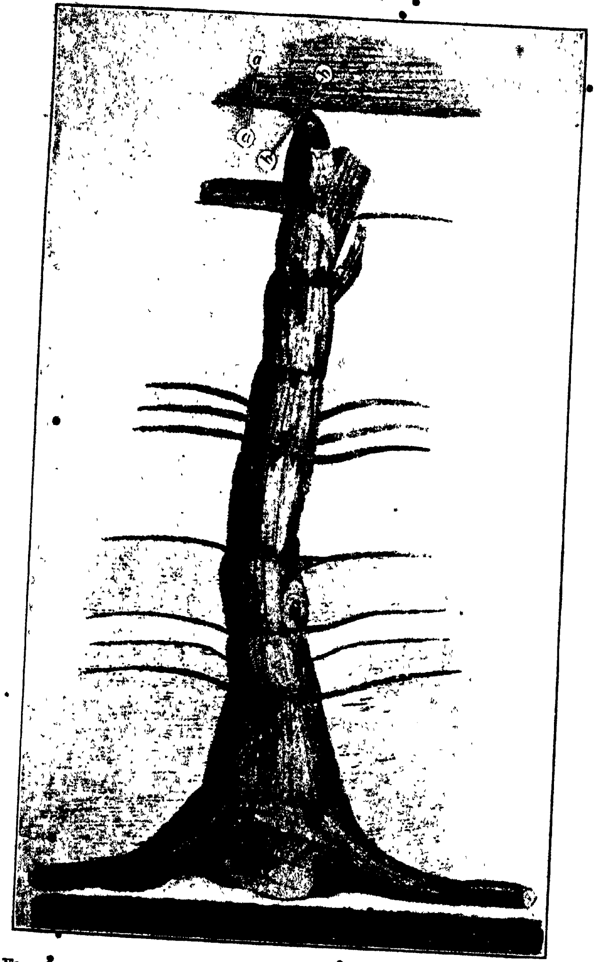


FIG. 4.—(1) Fossil tree found at a depth of 288 feet from the surface.

sometimes quite pale." The depth of colour is largely dependent upon the proportion of carbonaceous matter present. Sometimes, though rarely, the underclay has become greatly silicified and very hard; it is then known by the term "ganister."[1] The underclays constituted the ancient soils in which the cryptogamic forests grew, and witness to the terrestrial nature of formation of the coal, and in them are found remains of stigmaria (Fig. 3), which are the roots of the cryptogamic plants, while in

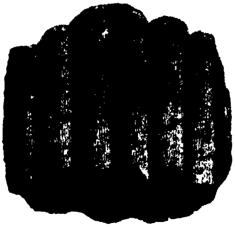


FIG. 4.—(2) Root or *stigmaria* of fossil tree.

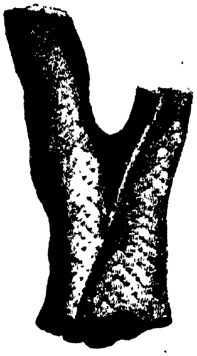


FIG. 4.—(3) Face of flattened part at top (*a a* to *b b*).

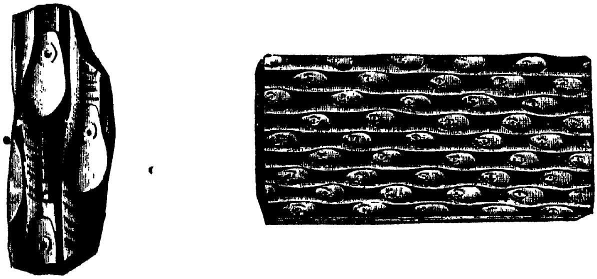


FIG. 5.—Fragment of *Sigillaria Grœseri*. The left-hand figure shows a small portion enlarged.

(Nicholson's *Manual of Palæontology*. W. Blackwood & Son.)

---

[1] Largely used to line "converters" in steel manufacture, owing to its very refractory character.

the overlying shales or roof of the seams are found the trunks, or sigillariæ (see Fig. 5), but no stigmariæ. In Fig. 4 is shown a fossil stem of such a "tree" found above the High Main seam at Killingworth Colliery in Northumberland, at a depth of 288 feet from the surface, sketched by the late Mr. Nicholas Wood,[1] the length of the fossil being about 11½ feet.

In the overlying roofs of coal-seams, when they are formed of shale, which is commonly the case, remains of ferns (Figs. 7 and 8) and flattened trunks of trees are very frequent, but never stigmariæ, all of which point to the one conclusion—that the underclays constituted the marshy ground, in which grew the forests of cryptogams. Other fossils characteristic of the true coal[2] measures are shown in Figs. 9, 10, and 11.

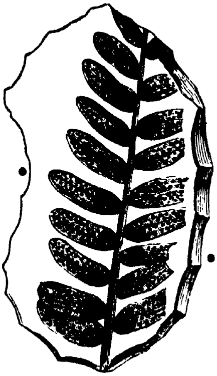


FIG. 6.—*Pecopteris elliptica.* (Nat. size.) Frostburg. (Sir C. Lyell's *Elements of Geology.* J. Murray.)

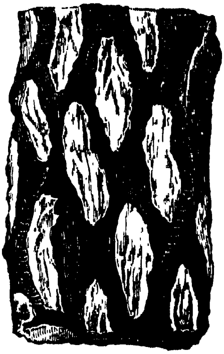


FIG. 7.—*Caulopteris primæva.* (Sir C. Lyell's *Elements of Geology.* J. Murray.)

When the extraordinary purity of some coals is considered, the percentage of ash in many instances being below 2 per cent., it is difficult to realise that it owes its origin to vegetable matter growing in swamps, as occasional inundations, one would suppose, would carry infiltrating mud into the swamps. The late Sir Charles Lyell[1] accounted for this by instancing the case of the Mississippi, and what is now taking place in deltas. "The dense growth of seeds and herbage which encompasses the margins of forest-covered swamps in the valley and delta of the Mississippi is such that fluviatile waters, in passing through them, are filtered and made to clear themselves entirely before they reach the areas in which vegetable matter may accumulate for centuries, forming coal if the climate be favourable. There is no possibility of the least intermixture of earthy matter in such cases." Thus, in the large submerged tract called the 'Sunk Country,' near New Madrid, forming part of the western side of the Mississippi, erect trees have been standing ever since the year 1811–12, killed by the great earthquake of

---

[1] *Transactions Nat. Hist. Soc. of Northumberland and Durham,* vol. i. p. 208.

[2] *Neuropteris, Pecopteris, Sphenopteris* are genera of ferns which are also extremely common in the coal measures.

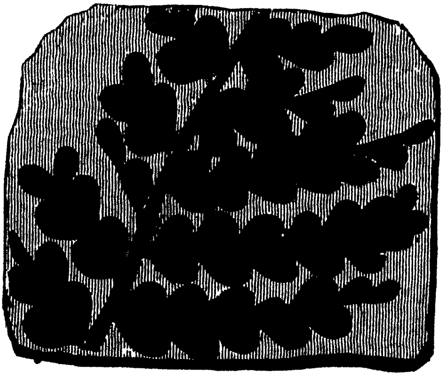


FIG. 8.—*Odontopteris Schlotheimii.*
(Nicholson's *Manual of Palæontology.* W. Blackwood & Son.)

---

[1] *Elements of Geology*, by Sir Charles Lyell, Bart., F.R.S., p. 393.

that date; lacustrine and swamp plants have been growing there in the shallows, and several rivers have annually inundated the whole space, and yet have been unable to carry in any sediment within the outer boundaries of the morass, so dense is the marginal belt of reeds and brushwood."

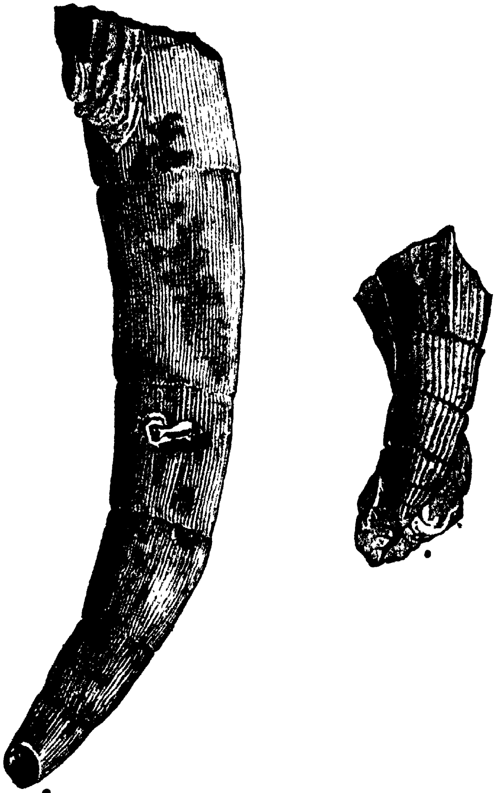


FIG. 9.—*Calamites Cannæformis.*
(Nicholson's *Manual of Palæontology.* W. Blackwood & Son.)

Bituminous coal is, then, chiefly derived from sigillaroid trees, ferns, &c.; and it is affirmed by some geologists, from the examination of microscopic sections of coal,

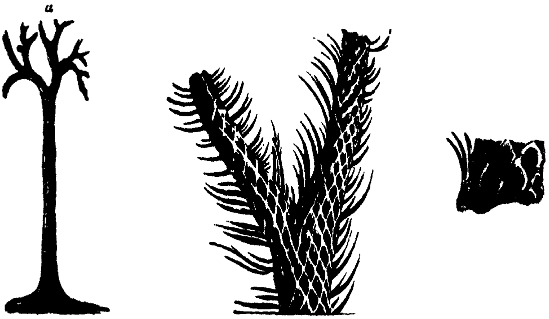


FIG. 10.—*Lepidodendron sternbergii.* Coal measures, near Newcastle. *a*, Branching trunk, 49 feet long; *b*, Stem with bark and leaflets; *c*, Portion of same, natural size, nearer the root.
(Sir C. Lyell's *Elements of Geology.* J. Murray.)

that it is in great measure composed of the spores of these plants, termed macrospores and microspores.[1]

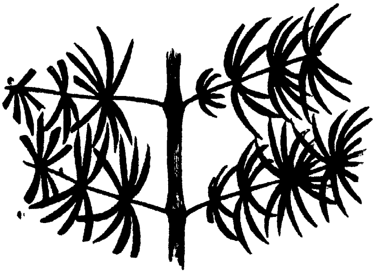


FIG. 11.—*Asterophyllites foliosus.*
(Nicholson's *Manual of Palæontology.* W. Blackwood & Son.)

**Varieties of Bituminous Coal.**—Under this heading may be included all those coals occupying a place between lignite at the one extreme, and anthracite at the other. Percy subdivided bituminous coals—he preferred the term "flaming" to bituminous—for economic purposes into—(1) Non-caking or fire-burning, being rich in oxygen; (2) caking; (3) non-caking, being rich in carbon.

---

[1] The late Professor Huxley, for instance, "Critiques and Addresses," *Contemporary Review*, 1870, p. 92.

A broad commercial classification would be—(1) Gas; (2) coking; (3) house; (4) manufacturing or iron smelting; and (5) steam coal—all of which grade one into the other, so that a coal occupying an intermediate place, say, for instance, between house and gas, would be termed a second-class gas coal, and would be sold either for gas-making or as a domestic fuel. The author has drawn up a series of tables showing analyses of high-class coals typical of each class, which can be used for purposes of comparison.

(1) *Gas Coal.*—This subject has already been treated under the heading "Cannel Coal" (see p. 14). A good gas coal should yield about 10,500 cubic feet of gas (at 60° F. and 30-in. bar), with an illuminating power equal to sixteen standard candles. The sulphur contents of the coal should be below 1 per cent., as, on distillation, it is emitted in combination with hydrogen as sulphuretted hydrogen, which is not only an evil-smelling and poisonous gas, but acts as an adulterant to the illuminating gases. Many gas coals are also sold as house coals.

TABLE VII.—*Gas Coals.*

| Name of Coal. | District. | Percentage Composition. | | | | | Percentage of Coke. | Yield of Gas per Ton of Coal in Cubic Feet. | Illuminating Power in Standard Candles. |
|---|---|---|---|---|---|---|---|---|---|
| | | Fixed Carbon. | Volatile Hydro-carbons. | Sulphur. | Ash. | Moisture. | | | |
| North Bitchburn | Durham . | 62·32 | 31·32 | 0·41 | 4·35 | 1·60 | 67 | 10,800 | 18·10 |
| Auchlochan Six-Feet Splint Coal | Lanarkshire | 49·96 | 37·14 | 0·34 | 4·26 | 8·30 | 67 | 10,580 | 22·18 |
| Mitchell Main . | Yorkshire . | 64·30 | 29·53 | 1·53 | 4·5 | 1·67 | 67 | 11,500 | 18·10 |

(2) *Coking Coal* is black and shiny, and usually friable; on heating, the coal swells up or intumesces. It burns with a short flame. If used for household purposes, the fire requires more attention in respect of poking and breaking up than an ordinary house-fire coal.

The cause of the caking or coking quality is not fully understood. Two coals may possess the same ultimate[1] analysis, and the one be of a good coking quality and the other not.

As coke is used mostly for metallurgical purposes, the coal from which it is made should be low in sulphur and phosphorus,[2] as these elements are injurious to the metals; and low in respect to ash contents also, as the ash not only limits the heating value of the coal, but increases the amount of slag produced.

The purest coke known is Ramsay's Garefield (Durham):—

| | Per Cent. |
|---|---|
| Carbon | 97·6 |
| Sulphur | 0·85 |
| Ash | 1·55 |

(3) *House Coal.*—It is difficult to exactly define a house-fire coal, as nearly all coals are used for domestic purposes, and many which are sold as gas and steam coals are also sold as "house-fire" fuel. The finest house coal ever put on the market was, probably, that obtained from the High Main seam at the Wallsend Colliery on the banks of the Tyne.

---

[1] The expression "ultimate analysis" is used to signify a more detailed and complete determination of the elements making up the coal than a "proximate analysis," which gives merely the percentage of fixed carbon, volatile hydrocarbons, sulphur, ash, and moisture, *e.g.* Table VIII. contains results of some "proximate analyses," whereas the first part of Table XI. gives "ultimate analyses" of steam coals.

[2] Although in the basic process of steel manufacture, so far as the phosphorus is concerned, this is not of so much importance; in fact, where the basic slag is profitably sold as manure, it may be a positive advantage that the coke should be high in phosphorus contents.

Table VIII.—*Coking Coals.*

| Colliery. | District. | Percentage Composition. | | | | | Percentage of Coke.[1] | Percentage of Phosphorus in the Coke. |
|---|---|---|---|---|---|---|---|---|
| | | Fixed Carbon. | Volatile Hydro-carbons. | Sulphur. | Ash. | Moisture. | | |
| **Brancepeth** . . | Durham | 67·31 | 25·61 | 0·78 | 5·10 | 1·20 | 72·8 | ·005 |
| **West Stanley** . . | ,, | 69·84 | 24·73 | 0·63 | 3·80 | 1·00 | 74·0 | ·0055 |

The following analysis of coal from the Hetton Coal Company's collieries in the county of Durham may well serve as a standard for comparison:—

| | Per Cent. |
|---|---|
| Carbon . . . . . . . . . . | 77·07 |
| Oxygen . . . . . . . . . . | 11·85 |
| Hydrogen . . . . . . . . . | 4·04 |
| Nitrogen . . . . . . . . . | 1·04 |
| Sulphur . . . . . . . . . | 1·28 |
| Ash . . . . . . . . . . | 2·44 |
| Water . . . . . . . . . . | 2·28 |
| Coke . . . . . . . . . . | 65·20 |
| Volatile matters . . . . . . . | 34·80 |

What are the requirements in a house-fire coal? It should be capable of producing a good bright fire—not too fierce, as would be the case with an iron-smelting, and, still more, with a steam coal, hence the fixed carbon contents should be below those of a steam coal. A coking coal does not, for reasons already stated, make a good house coal, and a coal high in sulphur is also undesirable. The ash produced in burning the coal should be small in quantity, grey and cindery, as compared with the soft, white powdery ash characteristic of a good steam coal. In Table IX. are given the proximate analyses of several well-known house-fire coals.

---

[1] These percentages were obtained in laboratory experiments, and it is doubtful whether more than 68 to 70 per cent. would be secured in actual manufacture.

TABLE IX.—*House Coal.*

| Colliery. | District. | Fixed Carbon. | Volatile Hydro-carbons. | Sulphur. | Ash. | Moisture. |
|---|---|---|---|---|---|---|
| | | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. |
| Lambton (Trebble Nuts) | Durham | 59·40 | 33·31 | 1·56 | 4·23 | 1·50 |
| Great Western (No. 3 Rhondda) | Glamorganshire | 72·19 | 24·58 | (0·74 [1]) | 1·64 | 1·59 |
| Cannock and Rugeley | Staffordshire | 48 | 33·59 | 1·06 | 3·01 | 14·10 |

(4) *Manufacturing or Iron-Smelting Coal.*[2]—Should be low as to sulphur and ash contents and high in fixed carbon, though in the latter respect below that of a first-class steam coal, unless the fuel is to be used under forced draught (iron smelting, for instance), in which case it would pay to purchase coke in preference to a smokeless steam coal or anthracite.

(5) *Steam Coal.*—The items of most importance in a steam coal are the heating power, the nature of the ash, and the amount of sulphur present. The heating power is very largely dependent on the carbon contents, but there should be sufficient volatile hydrocarbons present to allow of easy ignition and consumption of the fixed carbon. If the moisture is high a considerable quantity of heat is rendered non-effective, in that it is expended in evaporation. Sulphur acts detrimentally in eating away the fire-boxes; and ash, as it is an incombustible, reduces the value of a coal. The coal, on burning, should not form clinker, but leave a light soft ash, usually white, which protects the fire-bars from the heat of the fire without clogging or sticking to them.

---

[1] Contained in the ash and volatile matter.

[2] With the exception of some Scotch furnaces, and a few in North Staffordshire, little, if any, iron smelting is now done by coal.

The chief constituents of the ash of coals are silica, alumina, oxide and bi-sulphide of iron. Sexton gives the following as examples of the composition of ash from coals:—

TABLE X.[1]—*Composition of the Ash in Coal.*

| | 1. | 2. | 3. | 4. |
|---|---|---|---|---|
| Amount of ash | 5·52 | 6·94 | 2·91 | 14·72 |
| Silica | 40 | 28·87 | 34·21 | 53·00 |
| Alumina<br>Oxide of iron | 44·78 | 86·95 | 52·00 | 35·01 |
| Lime | 12·00 | 5·10 | 6·19 | 3·96 |
| Magnesia | trace | 1·19 | 0·66 | 2·26 |
| Sulphuric acid ($SO_3$) | 2·22 | 7·23 | 4·12 | 4·89 |
| Phosphoric acid ($P_2O_5$) | 0·75 | 0·74 | 6·63 | 0·88 |
| | 99·75 | 98·08 | 97·82 | 99·92 |

The lime and magnesia have a fluxing influence, and a high percentage of oxide of iron[2] may cause the ash to fuse into clinker, but the fusibility of an ash depends rather on the relative proportion of the several constituents than the presence of any one in excess.

**Anthracite** may be defined as metamorphosed bituminous coal, or coal from which nearly all the volatile matter has been expelled by heat, due either to pressure or the proximity of trap rock. Anthracite is glossy black, and when handled scarcely soils the fingers. It is hard, compact, and difficult to ignite, burning without flame or smoke, and giving out great heat. Its uses are chiefly for malting, where a steady heat is required, for hot-house stoves, iron smelting, and,

---

[1] *Fuel and Refractory Materials*, by A. H. Sexton, F.I.C., F.C.S., 1st ed., p. 76.

[2] The iron exists, of course, in the coal as iron pyrites, *i.e.* sulphide of iron.

TABLE XI.—*Composition of Steam Coals.*

| Colliery. | District. | Ultimate Analysis. | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Carbon. | Hydrogen. | Oxygen. | Nitrogen. | Sulphur. | Ash. | Moisture. |
| Navigation smokeless steam coal, Great Western Colliery. | Rhondda Valley, Glamorganshire. | 86·48 | 4·04 | 3·62 | 0·88 | 0·70 | 3·04 | 1·24 |
| Gwmamman smokeless steam coal. | Aberdare, Glamorganshire. | 91·11 | 3·95 | 1·55 | 0·90 | 0·52 | 1·97 | ... |
| Hastings Hartley Main steam coal, Seaton Delaval Colliery. | Seaton Delaval, Northumberland. | 79·63 | 5·05 | 10 75 | 1·02 | 0·75 | 2·81 | ... |

| Colliery. | District. | Proximate Analysis. | | | | Heating Value. | |
|---|---|---|---|---|---|---|---|
| | | Moisture. | Volatile Hydrocarbons. | Ash. | Fixed Carbon. | Calories. | Water Evaporated at 100° C. per lb. of Coal. |
| Navigation smokeless steam coal, Great Western Colliery. | Rhondda Valley, Glamorganshire. | 1·24 | 18·53 | 3·04 | 77·19 | 7755 | 14·44 |
| Gwmamman smokeless steam coal. | Aberdare, Glamorganshire. | 0·70 | 11·76 | 1·97 | 85·57 | ... | 13·93 |
| Hastings Harvey Main steam coal, Seaton Delaval Colliery. | Seaton Delaval, Northumberland. | ... | 34·17 | ... | coke 65·83 | 7709 | 14·35 |

latterly, it has come into great request for the generation of producer gas. In America, where the output reaches the enormous figure of 69,339,152[1] long tons, as against 3,171,346 long tons in the United Kingdom, anthracite is very largely used as a house fuel in some of the great towns to the exclusion of all other kinds of coal, hence the beautifully clear atmosphere of New York, Boston, and Chicago.

---

[1] These figures are for the year 1905.

In the following table the composition of a variety of anthracites is given. The best are those from South Wales, which produces the finest anthracite in the world. The calorific power of good anthracite is very great; taking the Garnaut Peacock vein coal (Carmarthen), for instance, it is 8624 calories, equivalent to 16·06 lbs. of water evaporated from and at 100° C. per pound of coal burned.

TABLE XII.—*Anthracite.*

| Name of Colliery. | District. | Proximate Analysis. | | | | Ultimate Analysis. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Moisture. | Volatile Matter. | Ash. | Fixed Carbon. | Carbon. | Hydrogen. | Oxygen and Nitrogen. | Sulphur. | Ash. |
| | | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. |
| Stanllyd Vein, Blaina | Carmarthen | ... | 5·09 | 1·15 | 93·76 | 92·53 | 3·61 | 1·96 | 0·75 | 1·15 |
| Pontyberem, "Big Vein" | ... | 0·82 | 4·06 | 0·84 | 94·28 | | ... | | ... | ... |
| | Pennsylvania, U.S.A. | 3·71 | 3·96 | 6·30 | 89·74 | | ... | ... | ·585 | ... |
| Zululand Colliery[1] | Hlabisa, Zululand | 2·00 | 5·50 | 8·75 | 83·75 | ... | .. | ... | | |
| | | 2·00 | 6·37 | 10·16 | 81·47 | ... | | ... | ·39 | ... |

---

[1] The seam from which this coal is got is 46 ft. 10 in. thick, of which 36 ft. 11 in. is coal, and 9 ft. 11 in. bands of stone.

# CHAPTER II

## DETERMINATION OF THE VALUE OF FUELS

**Determination of the Value of Coal.**—The determination of the ultimate analysis of coal is an important and somewhat lengthy process, necessitating great accuracy and a considerable knowledge of practical chemistry. The proximate analysis of fuels and the determination of their heat value can, however, be undertaken without any very difficult or advanced training in chemical practice, and provides the experimenter with much very necessary information, enabling him to determine with considerable accuracy the nature and value of the coal.

**Proximate Analysis of Coal.**—The sample, after being well mixed and quartered down, is ground in a porcelain mortar. The moisture, volatile hydrocarbons, and ash are determined, and the fixed carbon taken by difference.

*Moisture.*—10 grammes of the finely ground coal in a flat porcelain basin are heated in a water-bath until the weight is constant.

Loss in weight × 10 = percentage of moisture.

*Volatile Hydrocarbons.*—5 grammes of coal are placed in a special platinum crucible (see Fig. 12), the space above the inner lid being filled with charcoal in small pieces and an upper lid put on. The crucible is then heated gently over a Bunsen burner flame, and afterwards over a blow-pipe (Fletcher's Bunsen blow-pipe is the one generally used), until the flame from the crucible quite ceases. The crucible is then cooled, the upper lid with the charcoal removed, and the crucible and contents weighed.

Loss in weight × 20 = percentage of volatile matter, and deducting from this the percentage of moisture, the percentage of volatile hydrocarbons is obtained.

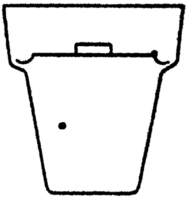


FIG. 12.

*Ash.*—The coke from the above experiment is then ground very fine in a porcelain mortar, and 1 gramme placed in a porcelain crucible (1¾ inches diameter) and heated over a Bunsen burner or in a muffle furnace until all the carbon is burned off; the crucible and contents are weighed, and the percentage of ash in the coal calculated therefrom.

Example :—

| | | Per Cent. |
|---|---|---|
| Moisture, 10 grammes, 30·70 − 30·50 = ·20 | ·20 × 10 . . . . | = 2·00 |
| Volatile matter, 5 grammes, 43·158 − 41·537 = 1·621 | 1·621 × 20 = 32·42 | |
| Coke . . . . . . . . . . . | 67·58 | |
| | 100·00 | |
| Volatile hydrocarbons . . . . | 32·42 − 2·00 | = 30·42 |
| Ash, 1 gramme; coke . | 10·794 − 10·674 = ·120<br>·120 × 100 = 12 per cent. ash in coke.<br>100 : 67·58 : : 12 : 8·11 per cent. ash in coal . . | 8·11 |
| Fixed carbon by difference . . . . . . . . . . | | 59·47 |
| | | 100·00 |

*Sulphur.*—As the sulphur exists in the fuel partly in organic combination, and in part as iron pyrites, and in some cases (especially where the coal has been subjected to the action of moisture) as sulphate, the percentage should be stated as a separate and additional item.

1 gramme of coal and 1·5 gramme of slaked lime are weighed into a platinum or porcelain crucible, thoroughly mixed, and moistened slightly with distilled water, then heated in a muffle furnace, or over a Bunsen flame, at a red heat until the carbon is entirely burned off, the contents emptied into a beaker containing hot water, and excess of hydrochloric acid (say, 5 cubic centimetres) added, boiled, settled, and filtered. The filtrate is boiled again, and then an excess of barium chloride solution added, the precipitate allowed to settle in a warm place, the filtrate decanted through a filter, and the precipitate on the filter washed with hot water until the washings give no precipitate on the addition of a drop of dilute sulphuric acid, even after standing five minutes. The precipitate and filter paper are then dried in the water-bath, and ignited when dry in a porcelain or platinum crucible, and the precipitate[1] weighed.

Weight of precipitate × 13·734 = percentage of sulphur in the coal.

*Iron.*—Occasionally it is necessary, though not often, to determine this in view of the nature of the ash. The ash[2] from 2 grms. of coke produced in the determination of the volatile matter is boiled in water with slight excess of hydrochloric acid, filtered, and the filtrate nearly neutralised with caustic soda solution. About 10 c.c. of potassium iodide solution (of a strength of 20 grms. per litre) is added, the contents transferred to a stoppered flask, which is then closed, and heated to between 120–140° F. in the water-bath for about twenty minutes; and after the addition of a little starch liquor, titrated with standard hyposulphate of soda solution (decinormal). The percentage of iron is then calculated, thus—

---

[1] The precipitate is barium sulphate ($BaSO_4$). The reason for the various stages in the process of the sulphur determination are obvious from the reactions, which are as follows:—

$2CaOH_2O + S + H_2O = CaSO_4$, with slaked lime and water,
$CaSO_4 + 2HCl = CaCl_2 + H_2SO_4$,
$H_2SO_4 + BaCl_2 = BaSO_4 + 2HCl$.

[2] It will be necessary not to ignite the ash too strongly or the dissolution of the peroxide of iron will become very difficult. Very little water should be used with the hydrochloric acid, say not more than an equal volume, and it will sometimes be necessary to allow the acid solution an hour or two to get all the iron dissolved, keeping it warm all the time on a sand or water bath. When the solution is complete, more hot water may be added and filtration be proceeded with.

$$\text{Cubic centimetres of solution required} \times \cdot005 \times 50 \times \frac{\text{per cent. of coke in coal}}{100}$$
$$= \text{per cent. of iron in coal; or—}$$

$$\text{Cubic centimetres solution required} \times \cdot0028 \times \text{per cent. of coke in coal} = \text{per cent. of iron in coal.}$$

The cost of a complete outfit of apparatus, reagents, &c., for carrying out promixate analyses as described above, is about £20.

**Determination of Specific Gravity of Coal.**—For this purpose the hydrostatic balance is most commonly used, and it should, for very accurate determination, be capable of weighing up to one-hundredth of a grain. The arrangement is shown in Fig. 13. A is a counterpoise which balances the pan B. The weight of the piece of fine thread C which holds the substance E, the specific gravity of which is to be found, is counterbalanced by placing a piece of equal length in the pan B.

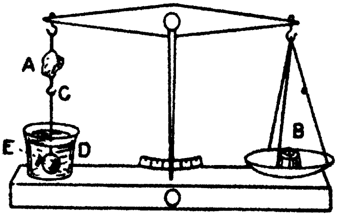


FIG. 13.

*D* is a beaker containing water at a temperature of 60° F. Then—

$$\text{If the weight of the substance in air} = W$$
$$\text{and} \quad ,, \quad ,, \quad \text{in water} = W'$$
$$W - W' = \text{weight of water displaced, and the specific gravity} = \frac{W}{W - W'}.$$

Thus the specific gravity of Newcastle coal is usually taken as 1·27, that is to say, it is 1·27 times heavier than water. The specific gravity of several varieties of coal are given, together with analyses, in Table XIII.

**Calculating Tonnage by Means of the Specific Gravity.**—Supposing it is desired to estimate with much accuracy the quantity of coal contained in a given area, proceed thus—

Area of tract, 1600 acres. Section of seam, 3 ft. 6 in.

Then 1 acre = 43,560 square feet and $43{,}560 \times 3{\cdot}5 = 152{,}460$ cubic feet, and $152{,}460 \times 1{\cdot}27 \times 62{\cdot}35 = 12{,}082{,}468{\cdot}87$.

$$\frac{12{,}082{,}468{\cdot}87}{2240} = 5349{\cdot}31 \text{ tons per acre.}$$

$$5349{\cdot}31 \times 1600 = 8{,}558{,}896 \text{ tons.}$$

In estimating coal resources it is usual to allow 1510 tons per acre per foot section of seam, but from this has to be deducted the loss occasioned by faults, nip-outs, and in working.

**Determination of "Calorific Power" and "Calorific Intensity" of Fuels.—Units and Terms.**—There are several units in use to express the heat value of fuels: (*a*) The British thermal unit (B.T.U.), or the amount of heat required to raise 1 lb. of water 1° F., *i.e.* from 60° to 61° F., which is the unit most commonly used in the United Kingdom; (*b*) the unit used in scientific work, or the heat required to raise 1 gramme of water through 1° C., *i.e.* from 0° C. to 1° C.; (*c*) or, sometimes, 1 kilogramme of water through 1° C., termed the Calorie, which is used in Continental practice; and (*d*)

**Table XIII.**—*Average Composition of British Coals, with their Weight, Bulk, Heat of Combustion, and Evaporative Power.*

(Compiled and deduced by D. K. Clark from the analyses and experiments of Messrs De la Bèche and Playfair, 1847–50.)

| Coals. | | Weight and Bulk. | | | | Composition. | | | | | | Coke produced from the Coals. | Total Heat of Combustion of 1 lb. of Coal. | | | Evaporative Power of 1 lb. of Coal from 212° by Trials. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | Equivalent Evaporative Power from 212°. | | |
| Averaged Groups. | Samples. | Specific Gravity. | 1 Cubic Foot Solid. | 1 Cubic Foot Heaped. | Bulk of 1 Ton Heaped. | Carbon. | Hydrogen. | Nitrogen. | Sulphur. | Oxygen. | Ash. | | Units of Heat. | From Water at 62°. | From Water at 212°. | |
| | | | Lbs. | Lbs. | Cubic Feet. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Per Cent. | Units. | Lbs. | Lbs. | Lbs. |
| **Welsh** | 37 | 1·315 | 82·0 | 53·1 | 42·7 | 83·78 | 4·79 | 0·98 | 1·43 | 4·15 | 4·91 | 73 | 14·858 | 13·46 | 15·52 | 9·05 |
| **Newcastle** | 18 | 1·256 | 78·3 | 49·8 | 45·3 | 82·12 | 5·31 | 1·35 | 1·24 | 5·69 | 3·77 | 61 | 14·820 | 13·29 | 15·32 | 8·01 |
| **Derbyshire and Yorkshire** | 7 | 1·292 | 80·6 | 47·2 | 47·4 | 79·68 | 4·94 | 1·41 | 1·01 | 10·28 | 2·65 | 59 | 13·860 | 10·43 | 14·34 | 7·58 |
| **Lancashire** | 28 | 1·273 | 79·4 | 49·7 | 45·2 | 77·90 | 0·32 | 1·30 | 1·44 | 9·53 | 4·88 | 58 | 13·918 | 12·62 | 14·56 | 7·94 |
| **Scotch** | 8 | 1·260 | 78·[illegible] | 50·0 | 42·0 | 78·53 | 5·61 | 1·00 | 1·11 | 9·69 | 4·03 | [illegible] | 14·164 | 12·75 | 14·77 | 7·70 |
| **Average of British Samples** | | 1·279 | 79·8 | 50·0 | 44·5 | 80·40 | 5·19 | 1·21 | 1·25 | 7·87 | 4·05 | 61 | 14·320 | 12·83 | 14·82 | 8·12 |
| **Anthracite, Ireland** | | 1·590 | 99·6 | 62·8 | 35·7 | 80·03 | 2·30 | 0·23 | 6·76 | —[1] | 10·80 | 90 | 13·302 | 12·55 | 14·50 | 9·85 |

[1] Included in ash.

the Centigrade unit (C.G.), or 1 lb. of water raised 1° C. These units can be transformed thus—

| | |
|---|---|
| (1) To convert a quantity of heat in C.G.s. into the corresponding value in B.T.U.s. | × 1·8 |
| (2) To convert B.T.U.s. into C.G.s. | × 0·5 |
| (3) To convert a quantity of heat given in kilos into B.T.U.s. | × 3·968 |
| (4) To convert B.T.U.s. into Calories | × 0·252 |

By *calorific power* is meant the absolute thermal effect produced in burning, which is measured by the amount of water (pounds, grammes, or kilos) which can be raised through 1° (Fahrenheit or Centigrade, as the case may be) by the combustion of 1 lb., gramme, or kilo of the substance, or, in other words, the number of units of heat produced in burning the substance in oxygen or air.

The *calorific intensity* is the pyrometrical heating effect manifest by the products of combustion.

**Determination of Calorific Power of Coal.**—1. *From Analysis.*—The elements in coal that generate heat when burned are carbon and hydrogen.

When carbon is burned to form carbon di-oxide ($CO_2$), there is a heat expenditure equivalent to 123,048 B.T.U.s.; as, however, twelve parts of carbon are necessary in the reaction—the combining weight of carbon being 12—the calorific power of carbon[1] (to $CO_2$) = 145,448 B.T.U.s.

When hydrogen is burnt to form water, the thermal value of the reaction $2H + O = H_2O$ is 12,304 B.T.U.s.; but as this is due to the combustion of two parts by weight of hydrogen, the calorific power will be 61,524.

Taking C, H, O, S to represent the percentage of carbon, hydrogen, oxygen, and sulphur contained in the coal, and CP to stand for calorific power—

---

[1] When carbon is burnt to form carbon monoxide, the thermal value is different; but as this would represent a state of incomplete combustion, the subject need not be further discussed here.

$$\text{Then}\quad CP=\frac{(C\times 14544)+(H\times 61524)}{100}\text{ in B.T.U.s.};$$

or, since the CP of H is 4·265 times that of C,

$$CP=\frac{(C+4{\cdot}265H)14544}{100}.$$

Oxygen renders useless one-eighth of its own weight (combining with the H to form water, – 8 of O to 1 of H), so the hydrogen which is available for combustion will be $H-\frac{1}{8}O$. Hence the formula can be stated thus—

$$CP=\frac{(C\times 14544)+(H-\frac{1}{8}O)61524}{100};$$

or thus—

$$CP=\frac{14544\left(C+4{\cdot}265\left(H-\frac{O}{8}\right)\right)}{100}.$$

For example, taking coal of the following analysis:—

| | Per Cent. |
|---|---|
| Carbon | 77·58 |
| Hydrogen | 6·15 |
| Nitrogen | 1·16 |
| Oxygen | 8·23 |
| Sulphur | 1·99 |
| Ash | 4·89 |
| | 100·00 |

$$CP=\frac{14544\left\{77{\cdot}58+4{\cdot}265\left(6{\cdot}15-\frac{8{\cdot}23}{8}\right)\right\}+\overbrace{1{\cdot}99\times 3996}^{\text{Sulphur.}}=14{,}458\text{ B.T.U.s}}{100}$$

$$=14{,}458\text{ B.T.U.s.}$$

*Evaporative Power*—This is sometimes calculated thus: As the latent heat of vaporisation is 967, *i.e.* 967 units of heat are required to convert 1 lb. of water at

212° F. into vapour of a temperature of 212° F. The *evaporative power* of carbon

$$=\frac{14544}{967}=14\cdot9\,;$$

that is, 14·9 lbs. of water would be evaporated by the combustion of 1 lb. of carbon.

In the case of hydrogen, each pound of hydrogen forms 9 lbs. of water, which, of course, must be evaporated, and as the products of combustion (by the nature of the conditions) will remain in the gaseous condition, the latent heat of steam must be taken into account, and

$$\text{EP of hydrogen}=\frac{61524}{967}-9=54.$$

However, the evaporative power of coals is usually determined directly from experiment.

2. *By Experiment.*—The heat-giving value of coals is usually determined by means of a Thompson's calorimeter, but the use of a Rosenhain apparatus is advisable as being more accurate. The modes of experimenting are as follows:—

1. *With Thompson's Calorimeter.*—Thompson's process consists in burning the sample of dried coal, usually 30 grains, with a mixture (300 grains) composed of three parts of chlorate of potash and one part of nitre. This oxygen-providing compound and the coal are thoroughly commingled, and placed in a copper cylinder (*a*) (Fig. 14), into which is also inserted a small fuse of cotton soaked in nitre. This combustion cylinder or furnace is held in the socket (*b*) and is covered by the copper hood (*c*), which is perforated at the bottom, and fitted at the upper end with a tube and stopcock; when passed over the furnace, the hood is pressed and held rigidly in position by the three springs (*d*). A beaker (*e*) is filled

with water up to a mark on the glass, which registers 29·910 grains, and the temperature of the same taken. The fuse is ignited, the furnace covered by the hood, the stopcock closed, and furnace and hood lowered into the water. As soon as the combustion ceases the stopcock is opened, the water agitated by working the instrument up and down twice or thrice, and the temperature again taken. The difference of the two temperatures, plus 10 per cent. allowance for heat lost in warming the instrument and by radiation, represents the evaporative power in pounds of water evaporated per pound of coal burnt.

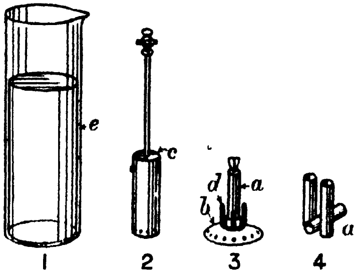


FIG. 14.—Thompson's Calorimeter.

It will be perceived that this is not a very accurate mode of determination. There is frequently difficulty in obtaining complete combustion of the fuel, and the 10 per cent. allowance for heat losses is somewhat of a convention. It is for this reason that the Rosenhain apparatus is to be preferred.

2. *Rosenhain's Calorimeter.*—Details of this apparatus are illustrated in Fig. 15. Practically complete combustion is secured, less than ½ per cent. of the substance escaping combustion, and as the sample burns under observation its behaviour as regards caking and clinkering may be studied. There are two types of apparatus:

(A) type, with ball-valve and brass vessel, which, with thermometer and accessories, costs £10, 3s., and the simple type (B), with glass vessel, which costs, complete, £7, 13s.

The author is indebted to the Scientific Instrument Company, Ltd., of Cambridge, for the following account of the method of using this apparatus :—

*Preparation of the Sample.*—Thoroughly clean the moulding press, insert the brass plate, and raise the screw. Fill the mould with powdered coal and insert the plunger, screwing it down as tightly as possible. Raise the screw and remove the mould. Slightly push the briquette with the plunger and it will leave the mould.

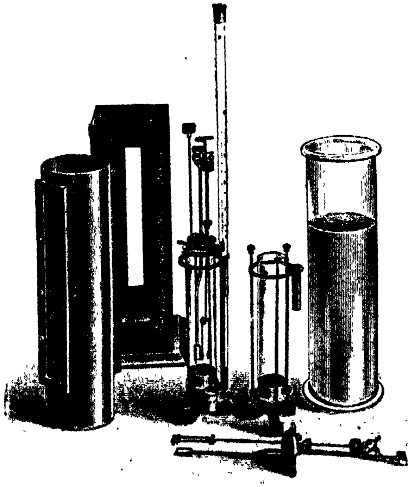


FIG. 15.—Rosenhain's Calorimeter.

*Introduction of Sample into the Calorimeter.*—Unscrew the three nuts locking the top plate. Turn the plate in order to free it from the supporting wires. Remove the plate and the lamp chimney. Place the sample of coal on the porcelain lid and put this on the base of the combustion chamber. Replace the chimney and top plate. (Care must be taken not to tighten locking screws too much.)

Before starting an experiment with instrument *A* it is well to see that the valve in the base is free. Place the platinum wire of the electric ignition against the coal sample. Insert the combustion chamber into the calorimeter. Connect the oxygen cylinder to the inlet tube of the combustion chamber by means of a rubber tube. Turn on a small stream of oxygen.

Fill the calorimeter vessel with about 2500 c.c. of water. (This water should be warmed nearly to the temperature of the room before using.) Place the open-scale thermometer in the spring fitting attached to the combustion chamber.

*The Combustion.*—The temperature of the open-scale thermometer is now read; if the temperature of the water has been properly adjusted to begin with, and the temperature of the room is fairly constant, this thermometer should remain almost stationary. The time and this temperature having been carefully noted, the electrical connection is made and kept on for a definite number of seconds—10 to 15 will be enough to ignite the sample. The current of oxygen is kept slow at first, but as the ash accumulates and tends to retard the combustion towards the end, the stream of oxygen is gradually increased as the experiment proceeds; very violent combustion is to be avoided, as smoke is liable to be formed; it is also apt to injure the platinum igniting-wire, and the latter is therefore best raised out of contact with the sample as soon as the combustion is well started. The duration of the combustion varies from 7 to 15 minutes, according to the quantity and quality of the coal burnt. When all the combustion has ceased, the oxygen supply is cut off, the valve raised, and the tap in the upper outlet tube opened; the water then flows into the combustion chamber and is allowed to fill it entirely; as soon as this is accomplished, the valve is lowered and the oxygen again turned on. The water is thereby forced rapidly out through the valve at the base of the combustion chamber, and the bubbles of gas following it cause it to mingle with the rest of the water in the calorimeter. The thermometer is now carefully read at short intervals until its maximum reading is attained, which is generally the case a few seconds after the water has been expelled from the combustion chamber. This reading and the time are noted and the entire instrument is allowed to cool, with a slight current of oxygen still passing, for a period of time equal to half of that which has elapsed between the commencement of the combustion and the maximum reading of the thermometer; the fall of temperature during this time is added, as a radiation-correction, to the apparent rise of temperature observed between the initial and maximum readings of the thermometer.

*Calculation.*—If $w$ be the weight of coal used, W the water equivalent of the calorimeter and contents, and $t$ the rise of temperature corrected for radiation, the calorific value of the coal is given by

$$C = \frac{Wt}{w}.$$

Example :—

Water equivalent = 3·270 grammes.
Weight of coal used = 1·425 "
Apparent rise of temperature = 3·34° C.
Radiation correction = 0·08° C.
Calorific value $= \frac{3270 \times 3\cdot42}{1\cdot425}$
= 7850 C.G.S. calories per gramme of fuel.

If the data are given in pounds weight and *degrees* Fahrenheit the same calculation gives the result in B.T.U.s per pound of fuel.

**Determination of the Calorific Intensity.**—It is not sufficient to know the actual heating power of a coal, the temperature which could be obtained in burning it under perfect conditions should also be known, that is, if burned in exactly the right amount of oxygen under such conditions as to render the combustion perfect and allow of no loss of heat.

The temperature depends on the amount of heat liberated, and on the nature and weight of the products of combustion. The products of combustion can be readily reduced to a water equivalent—that is to say, the weight of water which would require the same amount of heat to raise it 1°. Where $W$ = weight of the products of combustion and $S$ = its specific heat—

$$\text{The water equivalent} = WS\,;$$

and if $T$ = temperature,

$$\text{Then } T = \frac{CP}{W \times S} \text{ where } CP \text{ represents the calorific power.}$$

Thus 12 parts by weight of carbon produce in burning $12 + (2 \times 16)$ parts by weight of carbon di-oxide ($CO_2$) = 44; or 1 lb. of carbon produces 3·67 lbs. of carbon di-oxide if burned in 2·67 lbs. of oxygen. The temperature of the resultant $CO_2$, supposing it had the same *capacity for heat* as water, would be—the specific heat of water being unity—

$$\frac{14{,}544}{3{\cdot}67} = 3960.$$

But the specifie heat of water and carbon di-oxide are as 1 : 0·2163.

Hence the temperature of carbon di-oxide produced is as 0·2163 : 1 :: 3960 : 18,297° F., and 18,297 + 32 = 18,329° F. Again, two parts by weight of hydrogen produce 2 + 16 = 18 parts by weight of water. Therefore 1 lb. of hydrogen yields 9 lbs. of steam.

61,524 B.T.U.s have to be distributed over 9 lbs. of steam, produced by the combustion, the specific heat of the steam being 0·4805. But the 9 lbs. of water have to be converted into steam, which process absorbs 966 × 9 units of heat; and between 32° F. and 212° F., or during a rise of 180° F., the specific heat of the water is not 0·4805 but unity, hence—

$$\frac{61{,}524}{9} = 6836;$$

$$\text{and} \quad 6836 - 966 + (1 - \cdot 4805)180 = 5777.$$

$$\text{Then} \quad 0{\cdot}4805 : 1 :: 5777 : 12{,}021,$$

and $12{,}021 + 32 = 12{,}053°$ F., or the rise of temperature due to the products of combustion.

Or the calculation may be concisely stated thus—

$$\frac{61{,}524 - \{966 + (1 - \cdot 4805)180\}9}{9 \times 0{\cdot}4805} = 12{,}021.$$

The following formula may, therefore, be applied to coals containing the ordinary constituents :—

Taking W = quantity of moisture in 1 lb of coal,

$$CI = \frac{C \times 14{,}544 + (H - \tfrac{1}{8}O)61{,}524 - \{966 + (1 - 0{\cdot}4805)180 \times (9H + W)\}}{\{3{\cdot}66C \times 0{\cdot}2163 + (9H - W) \times 0{\cdot}4805\}100}$$

and to the result must be added the temperature at which combustion takes place.

The pyrometric heating power, burning the coal in air instead of oxygen, can be determined by adding to the denominator of the above formula $\{2{\cdot}66\,C - 8(H - \tfrac{1}{8}O)\} \times \frac{100}{23} \times \cdot 244$ (or if there be excess of air (E) there must be further added $E \times 0{\cdot}2377$). This formula being derived as follows: 1 lb. of hydrogen requires 8 lbs. of oxygen for complete combustion, there being 23 per cent. of oxygen in air—

23 : 8 : : 100 : 34·78.

That is, 1 lb. of hydrogen requires 34·78 lbs. of air for its complete combustion. In this amount of air 26·78 lbs. are nitrogen, for 100 : 34·78 : : 77 : 26·78, and the specific heat of nitrogen is 0·244, hence the CI of hydrogen must be divided by 26·78 × 0·244. And 1 lb. of carbon requires 2·67 lbs. of oxygen for complete combustion, which is contained in 11·61 lbs. of air, of which 8·9 lbs. are nitrogen, so that the CI of carbon must be divided by 8·9 × 0·224.

# CHAPTER III

## GEOLOGY APPLIED TO COAL-MINING

**Geological Succession.**—Reference has already been made on page 6 to the different horizons in the geological scale in which coal occurs. The relative positions will be better comprehended by reference to a condensed statement of the progressive series. The order which is now almost universally adopted by British geologists is that stated in accompanying table.

**Classification of Rocks.**—Rocks can be divided under two heads—sedimentary deposits, and those of volcanic origin. The materials constituting the sedimentary rocks have been laid down in regular beds or strata as a sediment, usually transported and deposited through the agency of water. On the other hand, volcanic or trap rocks are intrusive, having been thrust through existing strata in the form of dykes (see Fig. 36), and sometimes overflowing and covering the surface, or passing along the planes of bedding (see Fig. 37). The term volcanic rock is also capable of another meaning. A deposit may owe its origin to volcanic action, though in a sense it is a sedimentary deposit; thus the material forming many ash beds, though emitted from volcanoes, has been laid down by water. Geologists speak of such a formation as volcanic, though it is not an intrusive or trap rock. There is also a class of deposit which, though sedimentary in the strict interpretation of the term, is of a very different character to what we usually understand as a sedimentary rock, viz. glacial deposits, or those

formations which are due to the action of ice on pre-existing rocks. There are various kinds of glacial deposits, such as *morains* (terminal and lateral), erratics (or transported stones), *boulder clays*, and others, that of most common occurrence being boulder clay, a *glacial clay* containing ice-worn boulders, and frequently alluded to as *glacial drift*. In some instances the glacial beds are spoken of as re-arranged deposits, having been redistributed under water. The late Professor Green[1] has given a valuable classification of derivative rocks (which are either mechanically, chemically, or organically formed), omitting those of glacial origin, which is reproduced on p. 50.

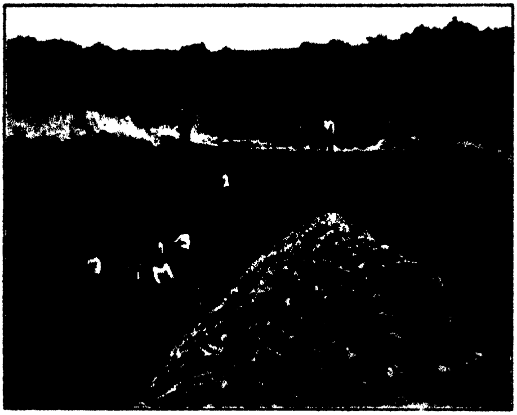


FIG. 16.—Outcrop of a Coal-seam. Quarrying Coal in New Zealand. (From a photograph by Mr. H. F. Bulman.)

**Explanation of Terms connected with Stratification.**—A bed or stratum may dip regularly in a positive direction, or it may be bent into a *syncline* or *anticline* (see Figs. 18, 19). Inversion may be produced by an anticlinical contortion, as shown in Fig. 18.

---

[1] *Physical Geology*, by A. H. Green, M.A., F.G.S., p. 181.

## TABLE XV.

*General Classification of Derivative Rocks.*

| | | |
|---|---|---|
| A. MARINE. | *Littoral.* | Mechanical.<br>Sandy and coarse.<br>Variable in horizontal range and irregularly bedded.<br>*Example:* Conglomerates and coarse sandstones. |
| | *Thalassic.* | Mechanical, or mixed mechanical and organic.<br>Clayey and fine.<br>Constant for large horizontal distances and irregularly bedded.<br>*Example:* Fine sandstones, shales, and impure limestones. |
| | *Oceanic.* | Organic.<br>Calcareous.<br>Often of great horizontal extent.<br>*Example:* Pure limestone.<br>Altered organic deposits.<br>*Example:* Atlantic red mud. |
| B. ESTUARINE. | | Mechanical.<br>Sandy and clayey rocks, and impure limestones.<br>Irregular bedding with frequent changes in mineral composition.<br>Alternations of marine, brackish, and freshwater beds, marine fossils often dwarfed. |
| C. LACUSTRINE. | *Fresh Water.* | Mainly sandy and clayey beds, and impure limestones of mechanical origin.<br>Organic or semi-organic occasionally.<br>Some chemical precipitates of carbonate of lime and silica. |
| | *Salt Water.* | Chemical precipitates, such as rock salt, gypsum, and dolomite, conspicuous; occurring in lenticular masses among sandy and clayey mechanical deposits.<br>Fossils rare, sometimes stunted and deformed marine forms. |
| D. TERRESTRIAL. | *Mechanical.* | From atmospheric weathering. Rainwash, screes, old soil. From wind (Æolian), blown-sand. |
| | *Organic.* | Mainly of vegetable origin as coal.<br>Mainly deposits of guano. |

Whatever the direction of the dip may be, it is always at right angles to the line of strike, or level course. When a rock is composed of very thin layers, as in the case of some shales for instance, the layers are termed *laminæ*, and the rock is said to be *laminated*; when it can be split up into thicker slabs, it is termed a *flagstone*. A bed may also be *irregular*, or, as when the sediment is deposited

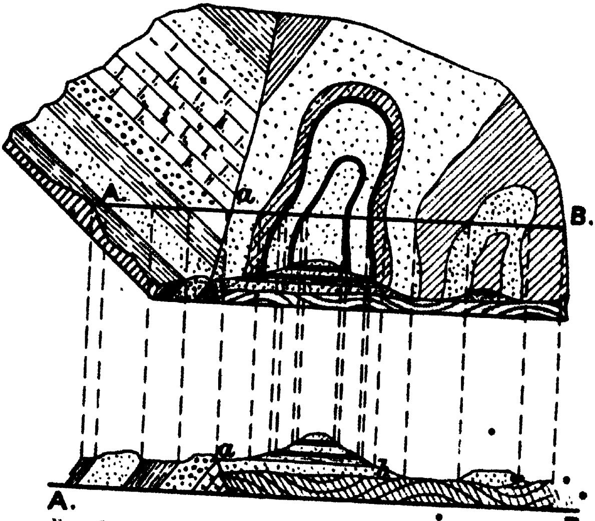


FIG. 17.—Plan and Section of a Model showing Stratification, Faulting (*a*), and Unconformity (*b*).

under varying currents, *false bedded*, and where it thins away in all directions like a lens it is termed *lenticular*.

Strata are *conformable* when they lie one above the other at the same inclination; but where beds lie on others having a totally different dip, or when an interval has occurred between the deposition of two groups, so that the one rests on the worn surface of the other (see Figs. 17 and 19), an *unconformity* is said to exist groups being unconformable in their relation to each other. Thus, for instance, there is an unconformity between the

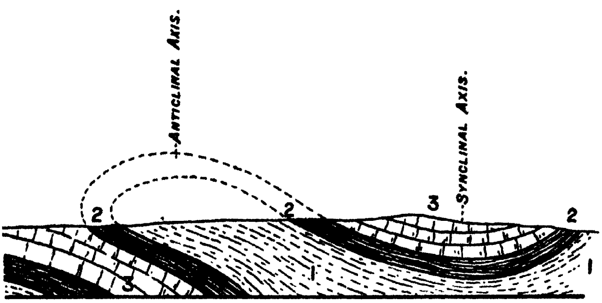


FIG. 18.—Contorted Strata showing Inversion.

Silurian rocks and the coal measures in South Staffordshire, the latter resting directly on the former.

As will be readily understood, the thickening and thinning of strata is of the greatest importance in mining generally, but of especial importance in coal-mining. Two seams of coal when widely separated vertically may be easily worked, but by a thinning out of the intervening strata may, in another district, be rendered both difficult

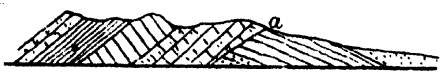


FIG. 19.—Unconformity (*a*), accompanied by Change of Dip.

and costly to mine, unless an entire thinning out of the dividing beds takes place, and the two or more seams unite to form one thick seam, as in the case of the South Staffordshire and part of the Warwickshire coalfield,—in which, however, the different horizons are marked in the coal by *partings* sometimes of shale or dirt, but frequently being merely divisional planes with little or no intercalated material.

**Cleavage and Jointing.**—Many rocks can be cleaved along their planes of bedding, but some are capable, as in the case of slate rock, of being split up into sheets at quite another angle, this structure being termed cleavage or *slaty cleavage* (see Figs. 20, 21). Cleavage has been produced by pressure, and the planes of cleavage are at right angles to the line of application of the pressure that produced them.

Joints are the natural fissures which traverse most rocks of a "freestone" character in all directions perpendicular to the planes of bedding; they constitute *lines of weakness*, and allow of such rocks being the more easily quarried. Quarrymen term them *water-veins*. Jointing is peculiarly characteristic of limestones and sandstones. Joints or breaks may have an important bearing on the method of working coal-seams, when occurring either in the roof, floor, or in the seam itself.

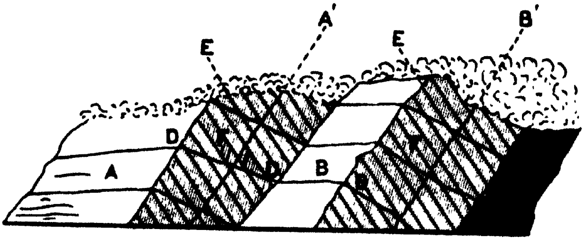


FIG. 20.—Stratification, Jointing, and Cleavage.
A B C. Faces of joints. A' B' being parallel joints.
D D D D. Lines of stratification.
E E. Lines of cleavage.
F F. Faces of cross joints or "pillaring."

**Vertical Cleavage or "Cleat" of Coal.**—Many coals are cut across by two sets of parallel planes of cleavage perpendicular to the planes of bedding, and more or less perpendicular to each other. Some geologists regard this *cleat*, as it is called, as similar to jointing, and others as more of the nature of cleavage. This cleavage is absent from some coals. The author has not observed it, for instance, in any of the Natal coals. Cleat is more marked in one direction than in the others. Thus in the Northumbrian and Durham coal-seams, the most marked facings have a course usually (roughly) north and south, and known as the *bordways cleat*,

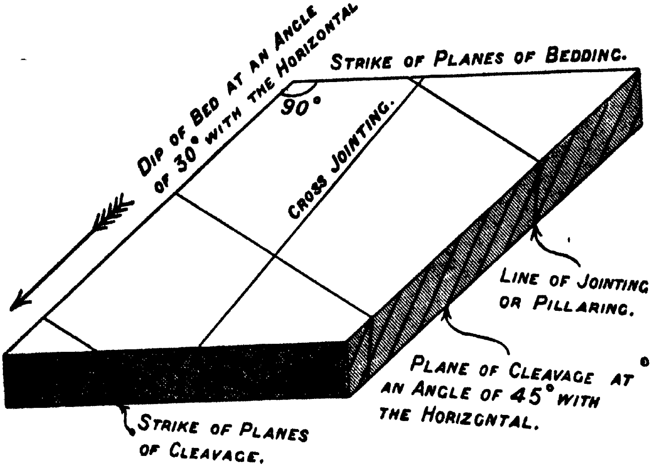

Dip of Bed at an Angle of 30° with the Horizontal
Strike of Planes of Bedding.
90°
Cross Jointing.
Line of Jointing or Pillaring.
Plane of Cleavage at an Angle of 45° with the Horizontal.
Strike of Planes of Cleavage.

FIG. 21.—Diagram illustrating Dip, Strike, Cleavage, Jointing, and Cross-jointing in a Bed of Slate.

the less determined or *headways cleat* having (roughly) an east and west course. Usually, therefore, when working by the "bord and pillar" system (known also by the name of "stoop and room"), the "bords" or wide places are driven at right angles to the bordways cleat, as, by so doing, the coal is more easily got and larger coal produced. For the same reason, when removing pillars ("working in the broken"), they are usually worked off in the same direction; and it is sought—subject to certain other circumstances, to which allusion will be made when treating of the longwall system of working (see vol. iii.)—to advance the longwall "on face" or bordways-way, instead of "on-end" or headways-way. When a *place* is driven neither "on end" or "on face," it is termed a *crosscut.*

**Geological Disturbances.**—(1) *Folding* (see Figs. 17, 18, 19, and 22), or contortion of the coal measures, if considerable, may prove a serious obstruction in the way of economical coal-mining, owing to the high angle at which the seams lie, and so necessitate sinkings of great depth to win them. Fortunately the coalfields of the United Kingdom, with few exceptions, are largely free from this form of disturbance. A portion of the North Staffordshire field, however, along the northern and in the central parts, has been subjected to folding, the strata having been bent into a double fold along synclinal and anticlinal axes, and the seams in places being so very highly inclined as to necessitate a special method of working (rearer working). The fields of Midlothian and Haddington also consist of a double trough, and in the Somersetshire field the coal measures are tilted up, and along the southern boundary even inverted; and in part of the anthracite region of the South Wales coalfield the seams have been subjected to considerable folding. But one of the most notable examples of contorted coal-seams is witnessed in the Franco-Belgian coalfield, where pit shafts sunk to work a given area frequently pass through the same seam several times (see cross section of the coalfield in the neighbourhood of Namur, Fig. 22). The strata have been subjected at the close of the coal period to great side pressure, and the seams crumpled up and broken by faults, the upper portion of the field having been denuded. It will be observed that at Namur the Devonian strata, have been bent over the coal measures; and at Liége so great has been the inversion that shafts have had to be sunk through the Devonian rocks in order to reach the coal below. The original width of the field has been much reduced by this compression, so much so that Professor Prestwich has estimated that the coal measures of the Liége field may have occupied, before compression, a width almost twice as great as that which they now possess. The deepest coal-mines in the world are situated in Belgium.

Besides enhancing the cost of mining and working the coal-seams, folding, in several instances, has brought about another notable effect, namely, the alteration of a highly bituminous coal into a "dry" coal, and into anthracite, of which metamorphic action a striking example is presented in the South Wales field (see page 10).

When cleavage is present in folded rocks the planes of cleavage and the axes of the folds are parallel, the pressure that produced the one being accountable for the other.

(2) *Faulting.*[1]—Faults, in the geological sense, or breaks in the continuity of the strata, constitute one of the most important features in structural geology, and greatly influence mining operations.

A simple fault is shown in Fig. 23, where the seam ($a$) has slipped down into the position $a'$, the line of slip being known as the *hade*, or in metal mining the *underlie*, and being measured by the angle made with the horizontal and the amount recorded in degrees, the vertical displacement or *throw* of the fault is measured

---

[1] The term fault is very loosely applied in mining; thus anything which interrupts or deteriorates the coal is often called a fault, whether it be due to intrusion of trap rock, swellies, rolls, nip or wash outs, or real faults. A fault is sometimes termed a dyke also, *e.g.* the "Ninety-fathom" dyke of the Northumbrian coalfield. Other names used in mining for a genuine fault are step, hitch, trouble, slip, or thing.

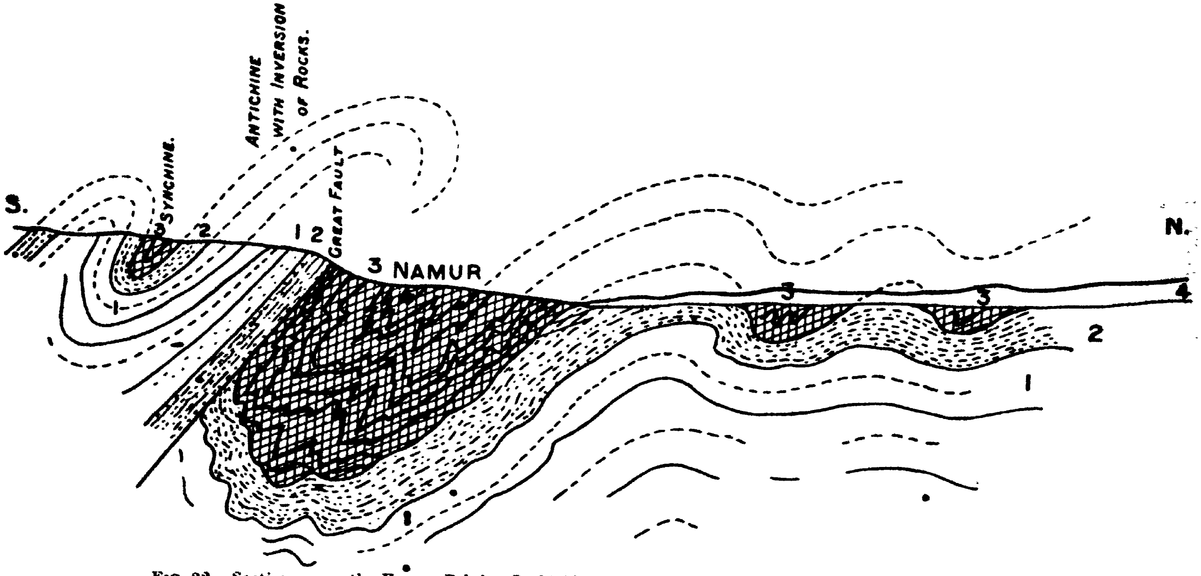


FIG. 22.—Section across the Franco-Belgian Coalfield, showing Anticline with Inversion, Syncline, and Fault.
1. Devonian ; 2. Carboniferous limestone ; 3. Coal measures ; 4. Cretaceous rocks.

in feet. The hade is often marked with scratchings or *slickensides*, and the opposing surfaces are highly polished, due to the attrition of the rock faces, especially if they are hard or crystalline; the fissure of the dislocation, or *leader*, is filled in with decomposed rock or clay, known as *leader stone*, and sometimes contains masses of spar, galena, or blende.[1] In metalliferous regions the *vein-stuff* in a fault is very often composed of siliceous or calcareous spares and ore. The hade may be very *flat*, in which case the area of barren ground along the course of the fault, in a given tract of coal, will be greater than if it were steep. Though, usually in inclined faults, the hade is in the direction of the down-throw side, cases do occur, more especially where the strata have been contorted, where the reverse is true, such faults being termed *over-thrust, over-lap*, or *reversed faults* (see Fig. 24). In such instances there is no accompaniment of barren ground. Where faults occur, as shown in Fig. 25, they are spoken of as *trough faults*.

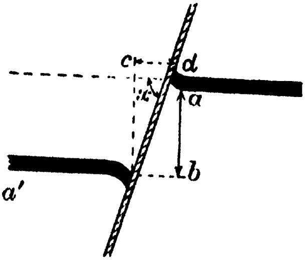


FIG. 23.—Ordinary Fault.

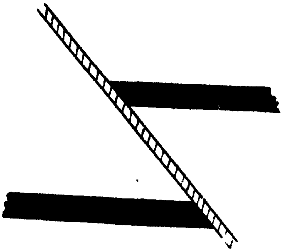


FIG. 24.—Reversed Fault.

---

[1] It is possible that in some of the coal-bearing areas of the United Kingdom these faults may occasionally prove to be the upper portions of ore-bearing veins. It would be interesting, for instance, and possibly of value, to know definitely whether or not some faults, lower down, develop into mineral lodes in the coal-fields of Northumberland, Shropshire, and Flintshire, in the neighbourhood of which, in the Carboniferous limestone formation, mines of galena, blende, and baryta have been or are being worked.

If, when working a stratum (coal, ironstone, fireclay, &c.) which is flat, or of moderate inclination, a fault is met with, the lost portion of the bed must be sought for in the direction of the greater angle, unless the fault is an over-thrust, when the reverse holds good; that is to say, the same point in the seam will be immediately above or below, unless there has been a *heave* or slipping to the right or to the left, and the lost part is picked up by sinking or drifting downwards or upwards. When the bed is highly inclined faults have to be considered as affecting the coal in the same way as they do mineral veins,[1] when, in order to pick up the lost seam, the miner will have to cross-cut to the right or left. This will be more clearly understood by the student if he will take two pieces of paper of the same shape and size, and draw on each a diagonal line from corner to corner, say left to right, these lines representing the highly inclined bed as seen in cross-section. Placing the pieces of paper

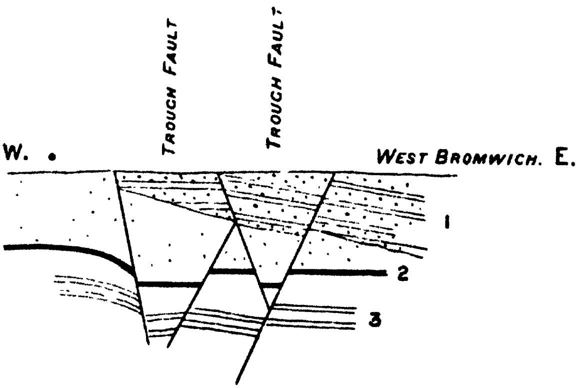


FIG. 25.—Trough Faults in the South Staffordshire Coalfield.

---

[1] In the South Wales field coal-seams are known as veins of coal.

against the window, so that the two lines can be seen, the one covering the other, move that nearest the vision a little way down; the position of the two lines will be as represented in Fig. 26, so that if *a* be the point in the bed in which the miner was working, in the dislocated part it will be at *a′*, and in order to recover the lost seam he will have to cross-cut or drift to *b*. If, however, as the paper is moved down it is so slipped to the right that the two lines are continuous, there will be no heave. Again, the heave may be such that it is necessary to drive to the right (see Fig. 28) or to the left (see Fig. 29) in order to pick up the lost seam.

Fig. 30 represents a plan of a highly inclined bed or seam faulted and heaved in the direction of the greater angle. There is no rule for positively determining the direction in which the lost bed can be discovered, but that devised many years ago by Schmidt (1810) and Zimmerman (1828) has been found to hold good in the great majority of cases, and may be applied as follows: Having obtained the dip and strike of both the seam and the fault, plot on paper the strike of both at two identical levels; thus, as in Fig. 31, the lines AB and CD represent the strikes of seam and fault at the same horizon. And A′B′ and C′D′ are the strikes of both at another level. A line joining the points BB′ will therefore be the line of the plane of intersection of seam and fault. Erecting at B from the opposite wall

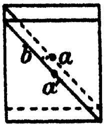


FIG. 26.

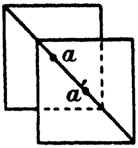


FIG. 27.

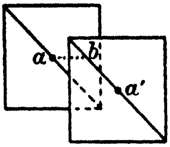


FIG. 28.

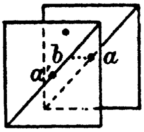


FIG. 29.

of the fault CD a perpendicular BE, and producing the intersecting line to F and G, it will be seen that BE is on the further side of FG, hence the lost seam

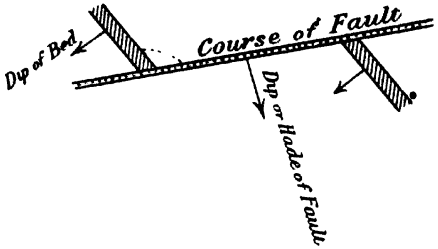


FIG. 30.—Plan showing Faulting of a highly-inclined Bed.

must be sought for in that direction; in Fig. 32 the reverse is the fact.

*Trough* faults are generally due to faults crossing

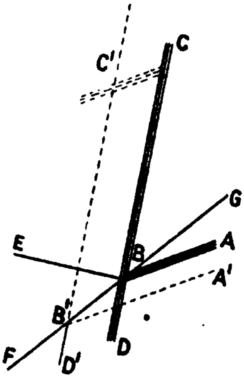


FIG. 31.

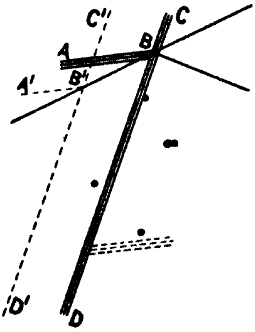


FIG. 32.

one another; in which case one of them will probably be older than the other. Faults end in various ways, by splitting up into a number of small faults, as in Fig. 33, by simply dying out as a rent, as exemplified by tearing a piece of cardboard, Fig. 34, or by one fault coming up directly against another, Fig. 35.

Contortions are frequently ended by faulting; the great Pennine fault in the North of England is an instance of this. A fault does not necessarily extend through the whole of the seams of a colliery. Thus at Towneley Colliery,[1] near the river Tyne, though the large faults generally go right through the measures, those of them which are less than 25 feet do not appear to reach the seams above and below that in which they occur (see p. 64, "rolls" and "swellies"). The author has observed the same feature in several coalfields.

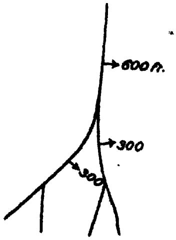


FIG. 33.

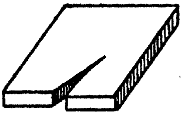


FIG. 34.

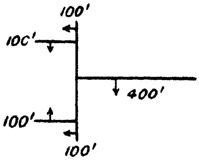


FIG. 35.

(3) *Dykes or Intrusions of Igneous Rock.*—Dykes often prove a great hindrance and cost in coal-mining where present in any great number, as, owing to the hard character of the intrusive rock, they are difficult and expensive to pierce, and frequently they have so altered the coal in their immediate proximity as to render it worthless (Fig. 36). They vary in thickness from a few inches to some hundreds of feet; sometimes they reach the surface and sometimes they do not. Intrusions of trap also take the form of overflows, in some cases covering the surface for miles with a thick capping, or occur as intrusive sheets

---

[1] Mr. J. B. Simpson, *Trans. N.E. Inst. M.E.*, vol. xxxviii. p. 53.

between the sedimentary strata (Fig. 37). The British coalfields, with the exception of the Clyde basin, are not much troubled with igneous intrusions. But in others they constitute one of the most important geological features. The South African coalfields, for instance, have been subjected to a greater extent perhaps than any others to the action of dykes, lateral intrusions, and overflows of dolerite, hardly a single colliery being free from interruption of this kind. In the Clyde basin, sheets of melaphyre and dolerite have been intruded amongst the coal strata, and have been the cause of much loss and difficulty in mining operations. There are, also, many vertical dykes of basalt and dolerite, the former being of Upper Carboniferous and, possibly, Permian age, the latter belonging to the Tertiary (Miocene) period.

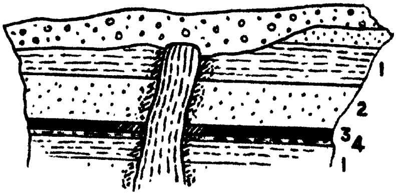


FIG. 36.--Dyke or Vertical Intrusion of Trap Rock.

A very notable lateral intrusion in Great Britain is the Great Whinsill[1] dyke, a sheet of basalt averaging from about 80 to 100 feet in thickness, the outcrop of which stretches across Northumberland from Greenhead on the west to a few miles north of Berwick on the east, the sheet probably underlying the whole of the southern and eastern portion of Northumberland; and it is exposed as a huge *inlier* in Upper Teesdale. A section at Bavington in Northumberland (Fig. 37) shows two intrusive sheets of basalt, which are, in all probability, branches of the Great Whinsill.

---

[1] See *Outlines of the Geology of Northumberland and Durham*, by Professor G. A. Lebour.

(4) *Wash-outs, Nip-outs, Rolls, and Swellies.*—When a portion of the strata has been denuded, and the cavity filled in with alluvium or drift, it is termed a *wash-out.* A wash-out of great extent is illustrated in Fig. 38. Some wash-outs or *nip-outs* are filled in with sandstone in place of gravel or sand, showing that the denuding action took place in Carboniferous instead of recent times (see Fig. 39). Such disturbances are by no means uncommon in our coalfields, and when working coal have sometimes been mistaken for faults; but slickensides, leader-stone, or other signs of movement are absent, and by driving straight ahead at the inclination of the seam, the coal is usually recovered at about the horizon it should theoretically occupy. A *swelley* or *balk*[1] is a bending or *roll* in a seam which may be due to a natural undulation of the bed, or may be caused by pressure of the same character as that which occasions faulting, and, indeed, these irregularities do sometimes partake of the character of faults proper. The eminent mining engineer, Mr. J. B. Simpson, mentions[2] a fault at Towneley Colliery, on the banks of the Tyne, of 12 feet throw, which occurs in the Towneley seam, but

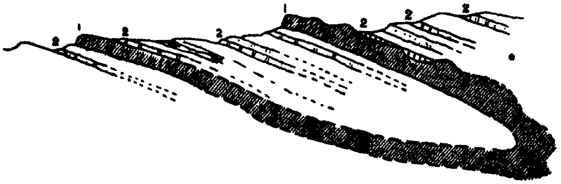


FIG. 37.—Section at Great Bavington, Northumberland (after Lebour).
1, 1. Whinstone. 2, 2. Limestones.

---

[1] The term "balk" is used indiscriminately to express a "nip-out" or "roll."
[2] *Trans. N.E. Inst. M.E.*, pp. 52–53, 55.

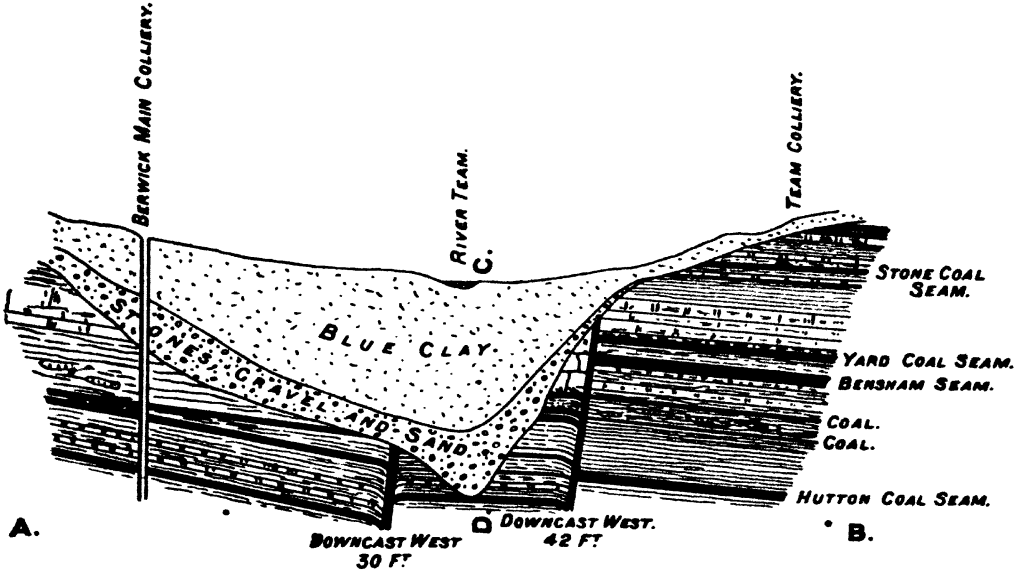


FIG. 38.—Section across the Team Valley (Co. Durham) along a line drawn from Berwick Main Colliery to Team Colliery.
Distance from A to B = 1 mile. Depth from C to D = 161 feet.

does not extend to the Five-Quarter seam 90 feet lower down; instead there is a swelley or bending of the latter nearly equal to the amount of the fault in the upper seam; and he recounts an interesting case at the same colliery, where the Towneley and Brockwell seams (180 feet apart) were free from faults, but in the intermediate Five-Quarter there was a nip-out of the seam for a width of 135 feet, extending over a distance of 600 feet, the seam being double its usual thickness for a breadth

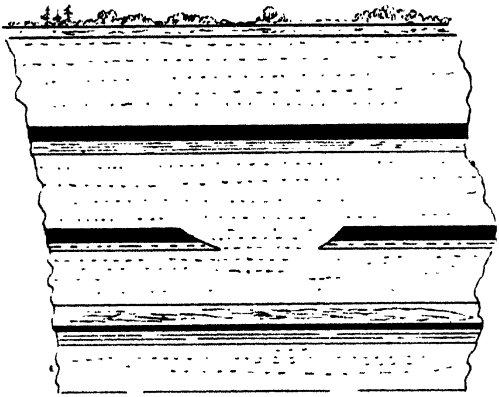


FIG. 39.—Nip-out.

about equal to that of the nip-out on one side only of the nip-out. This thickening of seams in the vicinity of nip-outs has often been remarked. So-called "nip-outs" are due, in some cases, to pressure (not fracture as with faults), and not to the denuding action of water.

**Measurement of the Inclination of Strata.**—When prospecting, the ascertainment of the true dip of the strata is a matter of great importance; the observed or *apparent dip* of beds exposed in a section is frequently, of course, not the *true dip*, the latter being in a direction at right angles to the water level course or *strike* of the beds. The dip is measured in degrees or, sometimes, in inches per yard, in percentages (*e.g.* 1 in 100), or by stating how much it deepens from the horizontal, vertical and horizontal measurements being given in the same terms (*e.g.* 1 in 20). These modes of reckoning dip can be converted, the one measurement into the other, by means of Table XVI., which is the work of the late J. Beete Jukes.

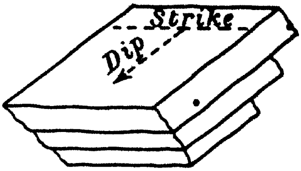


FIG. 10.

TABLE XVI.—*Nearest Degree of Dip, or each 1 in 100, answering to each Inch in a Yard.*

| Inches in a Yard. | In 100. | Nearest Degree. | Inches in a Yard. | In 100. | Nearest Degree. |
|---|---|---|---|---|---|
| 1 | 2·78 | 1½° | 19 | 52·82 | 28° |
| 2 | 5·56 | 3° | 20 | 55·60 | 29° |
| 3 | 8·34 | 5° | 21 | 58·38 | 30° |
| 4 | 10·12 | 6° | 22 | 61·16 | 32° |
| 5 | 13·90 | 8° | 23 | 63·94 | 33° |
| 6 | 16·68 | 10° | 24 | 66·71 | 34° |
| 7 | 19·46 | 11° | 25 | 69·50 | 35° |
| 8 | 22·24 | 12° | 26 | 72·28 | 36° |
| 9 | 25·02 | 14° | 27 | 75·06 | 37° |
| 10 | 27·80 | 16° | 28 | 77·84 | 38° |
| 11 | 30·50 | 17° | 29 | 80·62 | 39° |
| 12 | 33·36 | 19° | 30 | 83·40 | 40° |
| 13 | 36·14 | 20° | 31 | 86·18 | 40½° |
| 14 | 39·92 | 21° | 32 | 88·96 | 41° |
| 15 | 41·70 | 23° | 33 | 91·74 | 42° |
| 16 | 44·48 | 24° | 34 | 94·52 | 43° |
| 17 | 47·26 | 25° | 35 | 97·30 | 44° |
| 18 | 50·04 | 26° | 36 | 100·00 | 45° |

When the inclination is above 45° it is sufficiently expressed in yards, thus—2 yards in a yard, 3 yards in a yard, and so on,

and 1 in 1 = 45°
„ 2 in 1 = 63° about.
„ 3 in 1 = 71° about.
„ 4 in 1 = 76° about.

Let AB (Fig. 41) represent the line of intersection of the horizontal plane with the inclined plane, then AB = strike, the course or bearing of which is determined by the compass.

If the *surface* of a stratum is bared the strike can be determined by means of a clinometer, and the dip measured at right angles to it. If, however, the surface is covered and the stratum is merely exposed in section, and that not along a line at right angles to the line of strike, as CDE, the dip being an apparent one, made, say, on either the face CAE or CBE, the observed angle will be less than that of the true dip. If, however, it is possible to obtain the apparent dips along two faces, making a large angle with one another, the amount and direction of the full dip can be determined by calculation; thus:[1]—

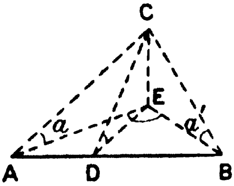


Fig. 41.

Let $a$ and $a'$ be the angles of the two apparent dips, viz. CAE and CBE, and D the angle of true or full dip CDE: the angle AEB = $2d$, and AED = $d - e$, BED = $d + e$, then—

$$\text{Tan } b = \frac{\sin (a - a')}{\sin (a + a') \cot a} \cot d.$$

$$\text{Tan D} = \frac{\sin (a + a')}{2 \cos d \cos a \cos a' \cos e}.$$

---

[1] See also *Geological Magazine*, x. 332; iii. 2nd ser. 377; *Physical Geology*, by Professor Green, and "Geology of the South Staffordshire Coalfields" (*Records of the School of Mines*, vol. i. part ii. pp. 330–335).

When a section has to be drawn obliquely to the true dip it is necessary to know what inclination to give to the beds. Beete Jukes worked out a table[1] (Table XVII. p. 70), which will be found useful in this respect. Thus, supposing the true dip of the strata is in a direction N. 10 E., and the line of section is drawn across the county N. 60 E., the difference in direction = 50°. If the amount of the true dip be 20° (the dip would be stated 20° N. 10° E.), the dip to be given to the beds in the section would be 13° 10′.

The trigonometrical formulæ on which this table is founded are worked out as follows:—

Let AB (Fig. 42) be the line of strike and AC the line of section.

Draw BC in the same horizontal plane as AB and AC. BC = direction of dip as given by compass.

Draw CD vertical to meet the surface of the bed in D.

Then the angle CBD ($y$) = the real dip.

Then the angle CAD ($z$) = the apparent dip.

Then the angle ACB ($x$) = the angle the section makes with the direction of the dip.

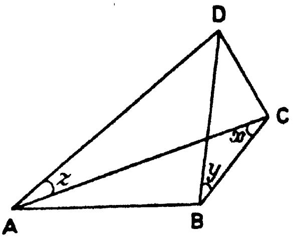


FIG. 42.

$$\text{Then } \tan y = \frac{CD}{BC}$$

$$\text{but } CD = AD \sin z,$$

$$\text{and } BC = AC \cos x,$$

$$= AD \cos z \cos x;$$

$$\therefore \tan y = \frac{\tan z}{\cos x} = \tan z \sec x,$$

or to radius $r$,

$$\left.\begin{array}{l} r \tan y = \tan z \sec x, \\ \text{hence } \log \tan y = \log \tan z \pm \log \sec x - 10 \end{array}\right\} \text{giving the true dip.}$$

$$\left.\begin{array}{l} \text{or } \tan z = \dfrac{r \tan y}{\sec x}, \\ \text{hence } \log \tan z = 10 \pm \log \tan y - \log \sec x \end{array}\right\} \text{giving the apparent dip, or that which will have to be drawn on the section.}$$

The following method of determining the direction and amount of the true dip from two apparent dips

---

[1] Oblique Section Table, as drawn up by J. Beete Jukes, M.A., F.G.S. See *Records of the School of Mines*, vol. i. part ii. p. 334.

TABLE XVII.—*Oblique Section Table.*

| Angle between the Direction of the Dip and that of the Section. | Angle of the Dip. | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10°. | 15°. | 20°. | 25°. | 30°. | 35°. | 40°. | 45°. | 50°. | 55°. | 60°. | 65°. | 70°. | 75°. | 80°. | 85°. | 89°. |
| 10° | 9° 51′ | 14° 47′ | 19° 43′ | 24° 40′ | 29° 37′ | 34° 36′ | 39° 34′ | 44° 34′ | 49° 34′ | 54° 35′ | 59° 37′ | 64° 40′ | 69° 43′ | 74° 47′ | 79° 51′ | 84° 56′ | 88° 59′ |
| 15° | 9° 40′ | 14° 51′ | 19° 23′ | 24° 15′ | 29° 9′ | 34° 4′ | 39° 2′ | 44° 1′ | 49° 1′ | 54° 4′ | 59° 8′ | 64° 14′ | 69° 21′ | 74° 30′ | 79° 39′ | 84° 50′ | 88° 58′ |
| 20° | 9° 24′ | 14° 8′ | 18° 53′ | 23° 39′ | 28° 29′ | 33° 21′ | 38° 15′ | 43° 13′ | 48° 14′ | 53° 19′ | 58° 26′ | 63° 36′ | 68° 49′ | 74° 5′ | 79° 22′ | 84° 41′ | 88° 56′ |
| 25° | 9° 5′ | 13° 39′ | 18° 15′ | 22° 55′ | 27° 37′ | 32° 24′ | 37° 15′ | 42° 11′ | 47° 12′ | 52° 18′ | 57° 30′ | 62° 46′ | 68° 7′ | 73° 32′ | 78° 59′ | 84° 29′ | 88° 54′ |
| 30° | 8° 41′ | 13° 4′ | 17° 30′ | 22° 0′ | 26° 34′ | 31° 14′ | 36° 0′ | 40° 54′ | 45° 54′ | 51° 3′ | 56° 19′ | 61° 42′ | 67° 12′ | 72° 48′ | 78° 29′ | 84° 14′ | 88° 51′ |
| 35° | 8° 13′ | 12° 23′ | 16° 36′ | 20° 54′ | 25° 18′ | 29° 50′ | 34° 30′ | 39° 19′ | 44° 19′ | 49° 29′ | 54° 49′ | 60° 21′ | 66° 3′ | 71° 53′ | 77° 51′ | 83° 54′ | 88° 47′ |
| 40° | 7° 41′ | 11° 36′ | 15° 35′ | 19° 39′ | 23° 51′ | 28° 12′ | 32° 44′ | 37° 27′ | 42° 23′ | 47° 35′ | 53° 0′ | 58° 40′ | 64° 35′ | 70° 43′ | 77° 2′ | 83° 29′ | 88° 42′ |
| 45° | 7° 6′ | 10° 4′ | 14° 25′ | 18° 15′ | 22° 12′ | 26° 20′ | 30° 41′ | 35° 16′ | 40° 7′ | 45° 17′ | 50° 46′ | 56° 36′ | 62° 46′ | 69° 14′ | 76° 0′ | 82° 57′ | 88° 35′ |
| 50° | 6° 28′ | 9° 46′ | 13° 10′ | 16° 41′ | 20° 21′ | 24° 14′ | 28° 20′ | 32° 44′ | 37° 27′ | 42° 33′ | 48° 4′ | 54° 2′ | 60° 29′ | 67° 22′ | 74° 40′ | 82° 15′ | 88° 27′ |
| 55° | 5° 46′ | 8° 44′ | 11° 48′ | 14° 58′ | 18° 19′ | 21° 53′ | 25° 42′ | 29° 50′ | 34° 21′ | 39° 20′ | 44° 49′ | 50° 53′ | 57° 36′ | 64° 58′ | 72° 55′ | 81° 20′ | 88° 15′ |
| 60° | 5° 2′ | 7° 38′ | 10° 19′ | 13° 7′ | 16° 6′ | 19° 18′ | 22° 45′ | 26° 33′ | 30° 47′ | 35° 32′ | 40° 54′ | 46° 59′ | 53° 57′ | 61° 49′ | 70° 34′ | 80° 5′ | 88° 0′ |
| 65° | 4° 15′ | 6° 28′ | 8° 45′ | 11° 9′ | 13° 43′ | 16° 29′ | 19° 31′ | 22° 55′ | 26° 44′ | 31° 7′ | 36° 12′ | 42° 11′ | 49° 16′ | 57° 37′ | 67° 21′ | 78° 19′ | 87° 38′ |
| 70° | 3° 27′ | 5° 14′ | 7° 6′ | 9° 3′ | 11° 10′ | 13° 26′ | 16° 0′ | 18° 53′ | 22° 11′ | 26° 2′ | 30° 39′ | 36° 15′ | 43° 13′ | 51° 55′ | 62° 43′ | 75° 39′ | 87° 5′ |
| 75° | 2° 37′ | 3° 58′ | 5° 23′ | 6° 53′ | 8° 30′ | 10° 16′ | 12° 15′ | 14° 30′ | 17° 9′ | 20° 17′ | 24° 8′ | 29° 2′ | 35° 25′ | 44° 1′ | 55° 44′ | 71° 20′ | 86° 9′ |
| 80° | 1° 45′ | 2° 40′ | 3° 37′ | 4° 37′ | 5° 44′ | 6° 56′ | 8° 17′ | 9° 51′ | 11° 41′ | 13° 55′ | 16° 44′ | 20° 25′ | 25° 30′ | 32° 57′ | 44° 33′ | 63° 15′ | 84° 15′ |
| 85° | 0° 53′ | 1° 20′ | 1° 49′ | 2° 20′ | 2° 53′ | 3° 30′ | 4° 11′ | 4° 59′ | 5° 36′ | 7° 6′ | 8° 35′ | 10° 35′ | 13° 28′ | 18° 1′ | 26° 18′ | 44° 54′ | 78° 41′ |
| 89° | 0° 10′ | 0° 16′ | 0° 22′ | 0° 28′ | 0° 35′ | 0° 42′ | 0° 50′ | 1° 0′ | 1° 11′ | 1° 26′ | 1° 44′ | 2° 9′ | 2° 45′ | 3° 44′ | 5° 39′ | 11° 17′ | 44° 59′ |

observed in sections in quarries, cliffs, or escapements will be found to be useful.

Supposing in Figs. 43, 44, and 45 the lines AB and

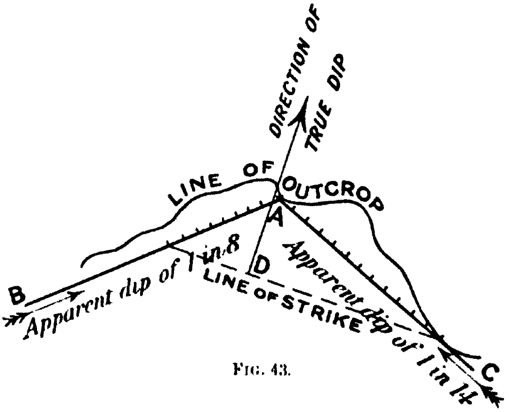


FIG. 43.

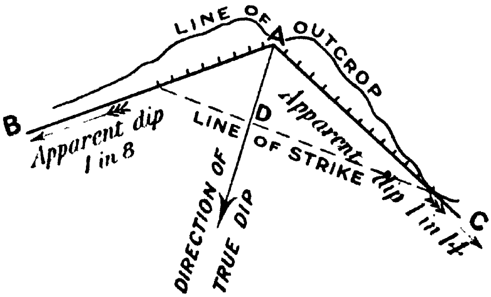


FIG. 44.

AC represent the direction of apparent dips as observed at the point A. In the first case (Fig. 43) the dip of BA is 1 in 8 toward A, that of CA 1 in 14 also towards A. Mark off on AB 8 units of lengths and 14 of similar units on AC. Join BC. BC is the line of strike, and the line dip will be in the direction D. The explanation of the other two figures is obvious. A similar method of ascertaining the dip is adopted in the case shown in Fig. 44, the dips being concurrent in these instances. But the case of Fig. 45 is different; here the apparent dips are in reverse directions. Project, therefore, one of the lines of dip—either will do—and mark off on the projected portion the number of units of dip—either degrees or other unit of inclination—joining the extremes as before. Thus projecting BA to D, join DC. DC is then the line of strike and EF the line of true dip.

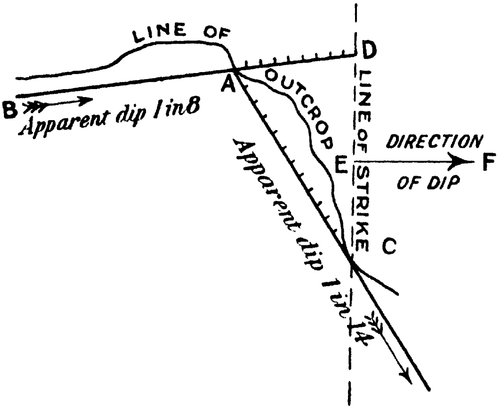


FIG. 45.

The directions of the lines of the apparent dip are determined by compass reading and plotted on paper by the aid of a protractor, the amounts of these dips being ascertained by a clinometer.

To find the amount of the true dip proceed thus (Fig. 46). Draw GH equal to AE (Fig. 41), and make the angle GHI equal to the angle of observed dip, namely, 3° (see Table XVI. p. 67)—exaggerated in the figure. Erect a perpendicular at G, meeting HI at I. Measure off along GH a distance GK equal to AD, and join KI. Then the value of the angle GKI, measured by the protractor, is the amount of the angle of true dip.

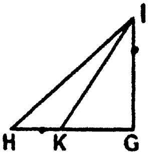


FIG. 46.

**Computation of Contents of Flat and Inclined Coal-seams.**—Allusion has already been made (p. 36) to the manner of ascertaining the tonnage of actual coal in a given area of seam. The formula generally adopted by the author for ascertaining the available tonnage when not unduly cut up by faults, dykes, nip-outs, &c., is to allow 1200 tons per foot thick per acre, as exhausting all the general hindrances and losses in working. An ample allowance, it will be perceived, is made for such losses, the difference between 1510 tons—the actual contents in an undisturbed acre of coal 1 foot thick—and 1200 being considerable. In computing the coal and other mineral contents in inclined beds proceed thus:—

Let A = the map area.
" B = Sec $\theta$, where $\theta$ is the angle dip of the bed.
" C = Thickness of bed in feet.
" D = The percentage of mineral obtainable.
" E = The number of cubic feet in 1 ton of the mineral. In the cases of coal this may be taken as 25.
" Q = The quantity in tons.

$$\text{Then } Q = \frac{A \times B \times C \times D}{E}.$$

The reason for this can be shown thus. If A′B (Fig. 47)

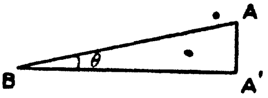


FIG. 47.

represent a line drawn across the area of the tract in the direction of the full dip, and AB represent the inclination of the seam, the angle ABA′ = θ,

$$\text{and } \frac{AB}{A'B} = \frac{\text{Sec }\theta}{1}$$

$$\therefore AB = \text{Sec }\theta \, A'B.$$

The amount of dip is variable; the strike is the same whether the seam is slightly or highly inclined.

**Concerning Stones and Clay.**—As building stones and clays are sometimes worked in connection with coal, being either quarried at the surface or mined in the colliery, and as they are used for colliery purposes,[1] or offered for sale, a few notes respecting the same will not be out of place in a work on coal-mining.

The principal stones at the present time generally used in the United Kingdom for building are granite, sandstones, and limestones.

The weight of stone should be such that the specific gravity is not less than 2 and not more than 3.

The resistance to crushing offered by a stone is of great importance, and varies according to the position in which the stone is placed in respect to its lines of bedding. That of "Gurnsey granite," for instance (of a weight of 180 to 185 lbs. per cubic foot), is 500 tons per superficial foot.

The texture of the stone has to be considered with regard to the use to which it is to be put, whether close grained or not, and its capability to withstand weathering influences.

The porosity, again, is an important factor; stones which seem to contain numberless holes sometimes take up less moisture than those which are close-grained.

---

[1] In Northumberland and Durham the colliery proprietors own the houses in which the workmen live, and frequently erect the schools, churches, chapels, &c. Many collieries throughout the United Kingdom have also extensive brick-works, the bricks being used at the surface and underground, and a trade often being carried on in the same as well.

Some stones are in a state of tension prior to being quarried, and are liable to expansion when separated from the bed. A well-known instance of this is the stone worked in the Booming Quarry of Kentucky, U.S.A. The more porous a stone the lower is its conductivity, and the more close-grained and compact the greater is its conducting power. But the conducting power of stones and rocks depends in great measure on the relative direction of the planes of bedding or of cleavage to the direction of application of temperature, so that, when the direction of the heat is perpendicular to the planes of bedding or cleavage, the conductivity of the rock is lower than when the two are parallel.

When selecting stones for building purposes, more especially in respect of slates, it is necessary to observe jointing, dip, and cleavage. The number of joints, for instance, determines the size of the slates, the cleavage their thickness; when not finely cleaved the stone may partake more of the nature of a flag than a slate.

Stone which contains a great amount of carbonate of lime is apt to harden after being quarried. An exception to this rule, however, is Portland stone, which is used in the manufacture of hydraulic cement.

The colour of stones, especially in the case of sandstones, is frequently determined by the presence of oxide of iron, though the very red sandstones as a rule contain less metallic iron than the grey sandstones. Sandstones are of varied colour—white, yellow, red, blue, green, brown, and buff.

Climatic conditions largely govern the use of stones. Thus, some stones used for building in the South of England, the Bath Oolite, for instance, would not be a suitable stone to use for erections in say Newcastle-upon-Tyne, where the sulphurous and other acids there generated from the large consumption of coal, chemical works, &c., would act injuriously on it, and for this reason it is best to avoid sandstones which contain even a trace of lime if they are intended for use in the neighbourhood of large manufacturing towns.

There need be very little waste in the quarrying of some stones. For instance, after a large block of granite has been "squared" for some heavy piece of masonry the refuse may be used for road metal, but on being crushed for that purpose a considerable amount of very small stone will be made, which may be used in concrete or the manufacture of artificial paving stones. At Mount Sorrel a considerable part of the waste is used as a fertiliser for fruit trees, as it contains both potash and soda.

No less than half a million tons of the granite annually obtained from the Leicestershire quarries is used on roads and streets in the Midland counties.

Limestone is used as a flux in smelting, the resulting slag often being employed as road metal.

Basalt "setts" are used in road-making.

Clays are of different kinds and are used for making a variety of bricks. A good building brick-clay should not contain more than 2 per cent. of potash, as tending to make the clay run, as do also soda and iron when present. Highly siliceous clays are employed to make fireclay or fireclay bricks.

# CHAPTER IV

## PROSPECTING AND BORING FOR COAL

**The Search for Coal.**—Perhaps enough has been said, or indicated, in the foregoing chapters to show what an important part the science of geology plays in the discovery and determination of the extent and value of coal deposits. Formerly coal was recklessly sought for in almost every geological formation, and much waste of money occasioned in useless boring and sinking operations. Now, however, in the United Kingdom and in many foreign countries, the coalfields have been geologically surveyed, and many of them accurately mapped in great detail, so that, by the scientific use of this information, the mining engineer and others are able to determine what seams of coal, beds of ironstone, and fireclay are likely to exist under any given area; and to know what succession of strata is likely to be penetrated should boring operations be carried out; and to decide upon the best site for shafts should sinking be determined on. There yet remain, however, many parts of the world in which the mining engineer will have to carry out his own geological investigation and mapping.

The search for coal, therefore, is differently commenced according to the nature of the information available with regard to the locality in which the exploration is to be made.

The subject can be considered under three heads:—

1. Where there is no knowledge of the presence of coal in the district to be explored.

2. Where coal is supposed to exist some little distance from the locality.

3. Where coal is worked in adjoining properties or royalties.

In case No. 1 it will be necessary to make a general topographical and geological survey of the country, where every feature which will prove of the least value as indicative of formations favourable to the occurrence of coal should be carefully noted, such as the occurrence of the fossil plants already mentioned, the existence of ochcrous springs, variations in vegetation, and many others. If the result of the survey is favourable, and coal is believed to exist, boring operations should be carried out in carefully selected spots.

In case No. 2 the supposed occurrence of coal should be carefully investigated and the neighbourhood geologically surveyed, the dip of the strata, especially, determined with accuracy, and the survey connected with the tract in question. If the coal measures dip in that direction, it will be desirable to put down bore-holes to determine the number, thickness, and value of the seams.

In case No. 3, by means of the vertical section at the nearest shaft and surface levelling to the property to be developed, a sectional levelling should be constructed, and if the distance be not great, and the coal-seams and other strata regular and unlikely to undergo variation, and there is no external evidence of large faults or intrusive dykes intervening, sinking operations may be undertaken without first putting down trial borings, though even in instances of this kind borings are often made before undertaking a costly sinking.

The importance of keeping accurate and detailed accounts of the strata passed through in boring—detailed in point of description of rock, thickness, colour, texture, and character generally—cannot be over-emphasised. Fig. 48 illustrates this in respect of three bore-holes, none of which has directly proved the existence of

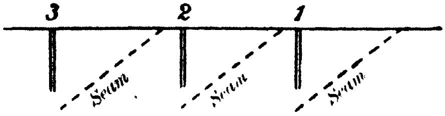


FIG. 48.

a seam of coal, though there are such outcropping between the several holes. Had a proper boring record been kept when putting down the first hole, the second would have shown the necessity of boring deeper, and the third would not have been necessary.

**Some Uses of Bore-holes.**—The uses to which bore-holes are put in coal-mining are numerous, and may be summarised as follows :—

1. The ascertainment of the existence, depth from the surface, nature, thickness, dip, and strike of a deposit.

2. To drain a shaft of water when the same is being sunk to workings immediately below.

3. For ventilating a shaft when being sunk to workings below.

4. To drain off gas from workings, or to otherwise ventilate workings.

5. For the purpose of obtaining water to supply dwellings in the neighbourhood of the colliery, or for the generation of steam, or other purposes.

6. For the purposes of carrying down the means of signalling or transmission of power, or conveying water to underground workings.[1]

7. For the insertion of pipes for the circulation of

---

[1] See the *Colliery Engineer*, vol. viii. pp. 49–52, for an interesting account of bore-holes being used in the anthracite coal districts of Pennsylvania as rope, steam, and water ways, as well as for speaking tubes, and for bell wires to enginemen on the surface.

freezing mixtures, when sinking shafts through running sands, &c.

8. To sink shafts.

Besides the uses to which bore-holes are put in coal-mining, it may be mentioned that in other branches of mining and engineering they are also largely employed, thus—to prove mineral lodes, obtain natural gas, for oil, salt, and artesian wells, for the introduction of cement for strengthening foundations, and to make holes for piling.

**Particulars concerning some Important Bore-holes.**—Important examples of some deep bore-holes may be mentioned:—

The Rand-Victoria bore-hole, put down south of the Simmer and Jack gold-mine (Transvaal), 4100 feet from the outcrop, struck the reefs at 2343 and 2391 feet. The total depth of the hole was 2500 feet.

A bore-hole was put down at a distance of 6000 feet from the outcrop at the Meyer and Charlton gold-mine (Transvaal) to a depth of 3500 feet.

The "Turf Club Syndicate," in the Transvaal, began two bore-holes near Johannesburg before the war, known as the East and West bore-holes; that to the west cut through the Reef series at 4743 feet from the surface, and the east bore-hole at 4825 feet. All these holes were bored by the diamond drill.[1]

Mr. Hennen Jennings has informed the author that experiments with a view to determining the heat increment were made in the west bore-hole, but not to the full depth, so that conclusive results had not been obtained, but when carried out over the whole depth they were not expected to materially differ from those arrived at in the Bezuidenville bore-hole, where the rise in temperature averaged 1° F. for every 208 feet in depth, over a depth of 3251 feet.

---

[1] See also p. 187.

In Wisconsin, U.S.A., a hole was bored by the American rope-drilling process to a depth of 3700 feet in search of mineral gas. It is worthy of note that by this method of drilling in ten years (1878–1888) no less than 30,000 oil wells were sunk.

The boring at Seaton Carew, near Hartlepool, in the county of Durham (1888), to prove the existence of salt (which, however, it did not do), was sunk to a depth of 1600 feet by the diamond drill.

A noted bore-hole was that at Schladebach, Leipzic, 5736 feet deep, commenced at 11 inches in diameter, and finished at 1·22 inches (at bottom). It began in the Triassic formation, and passed through the Permian into the Devonian, and was completed in 1888.

The bore-hole which definitely proved the existence of the Kent coalfield (1895), the possible existence of which had been years before suggested by Mr. Goodwin-Austin,[1] was sunk by diamond drill from the bottom of a shaft 44 feet deep, and attained a depth of 2286 feet 6 inches. It was commenced at 18 inches diameter, reduced to 9 inches, the final core brought up being 4 inches in diameter.

The deepest bore-hole in the world is that known as the No. 5 at Paruschowitz, near Rybnik, in Upper Silesia,[2] which went down 6572·6 feet. The first 351 feet of the boring were accomplished by a cutting edge and a stream of water through sand, clay, and Tertiary shales: the remainder of the hole was bored with the diamond drill, commencing with a crown 6·73 inches outside diameter. The diameters of the other crowns used were: at 1046 feet, 4·57 inches; at 1873 feet, 3·58 inches; at 3327 feet to the bottom of the bore-hole, 2·72 inches. Mannesman seamless steel tubes were used for lining the hole. The total weight of the bore-rods at 6561 feet was 13 tons 15 cwts., from which depth it took 10 horse-power to draw them, and the same to lower them in again—a 25 horse-power engine at this depth replacing one of 15 horse-power. Actual boring absorbed 399 working days, and the cost of putting the hole down was £3760, or about 11s. 5d. per foot. The boring cut through no less than 83 seams of coal. The average heat increment was at the rate of 1° C. for each 112 feet in depth.

---

[1] Report to the Royal Commission on Coal, 1871.

[2] *Glückauf*, 1895, vol. xxxi. pp. 1273, 1277.

The deepest coal boring yet carried out in the United Kingdom is that at Southcar, near Doncaster,[1] it being 3195 feet 3 inches deep. The work of boring was performed by the Vivian Diamond Boring Company, and was completed in 1896. The hole was 13 inches in diameter at the surface, gradually reduced by stages, the core from the bottom being about 1½ inches in diameter. The object of the boring was to prove the eastern extension of the Midland coalfield, in which respect it was successful.

### SYSTEMS OF BORING

Boring is either percussive or rotary, and all systems can conveniently be classed under one of the following eight heads:—

| | |
|---|---|
| 1. Boring with rigid rods. | Percussive boring. |
| 2. Rods with a "free fall" arrangement. | |
| 3. „ „ spring arrangement. | |
| 4. Rope-drilling. | |
| 5. Boring by hydraulic force. | |
| 6. The diamond drill. | Rotary boring. |
| 7. Drilling with the use of a steel cutting crown. | |
| 8. Drilling with chilled steel shot. | |

---

[1] *Trans. Inst. M.E.*, vol. xii. pp. 515–524.

In making a selection of the system of boring to be adopted in any one instance, the engineer should be largely guided by the object for which the bore-hole is intended. Rapidity of execution is always desirable; but more important than this may be accuracy in determining the section of strata, or the securing of as complete a core as possible.

As many of the older methods of boring are still largely used, it will be advisable to consider the methods and apparati in use under two heads, viz.: (1) Older methods of boring. (2) Later developments in boring.

## OLDER METHODS OF BORING

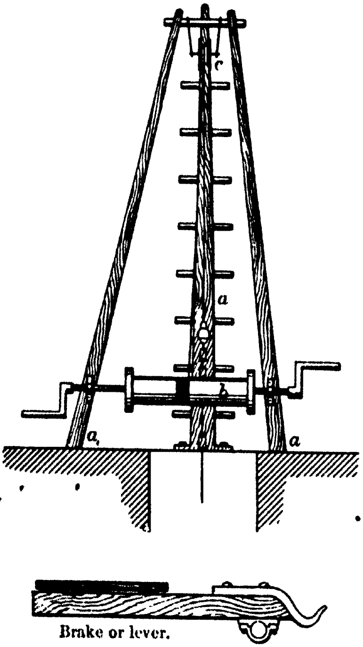
**Boring with Rigid Rods.**—The oldest method of boring in Britain is by raising and letting fall again iron or steel rods, screwed into one another, to the lowest length of which is attached a cutting-bit or chisel; and the same mode is still pursued, and may frequently be more cheaply employed than any other system, when the depth to which the hole has to be bored is not great, and when accuracy of section or a core of the strata passed through are not necessary.

Boring with rigid rods can, up to a depth of about 120 feet, be done by hand, between this and 300 feet by lever or "brake," but beyond 300 feet steam-power must be utilised.

The ordinary equipment, the various items of which are illustrated by Figs. 49 and 50, comprises—

1. A set of shear legs, made of Norway spars 8 inches square, from 40 to 50 feet in height, set on a triangular frame (*aa*, Fig. 49).
2. A jack roll, about 12 inches in diameter, fitted with a brake to regulate the speed of the rods when being lowered (*b*, Fig. 49).
3. Blocks and rope; the former either single, double, or multiplied according to the depth of the hole and consequent weight of the rods (*c*, Fig. 49, and 8, Fig. 50).

4. A simple lever of memel fir, 10 to 12 feet in length, the full crown, which is an iron axle, being situated 18 inches to 2 feet from the end at which the rods are suspended from an iron crook by a piece of rope, which is doubled and passed over the brace-head at the top of the rods. As the weight of the suspended rods increases, the length of the lever can be increased and a balance weight attached to the longer arm.(Fig. 49).



Brake or lever.

FIG. 49.—Head Gear or "Rig" in position.
a. Shear legs; b. Jack roll;
c. Block and rope.

5. A brace-head fitted to the top of the rods to enable them to be raised and turned in the hole (1, 2, and 3, Fig. 50).
6. A runner (5, Fig. 50).
7. A topit (4, Fig. 50).
8. Keys (15, Fig. 50).
9. Rods in 6-feet lengths, and made square (usually 1 inch square) so as to screw and unscrew easily (11, Fig. 50).
10. Chisels, or bits of steel, usually 18 inches long and 2½ inches broad at the face (14, Fig. 50).
11. Wimbles 3 feet long, the lower 2 feet being cylindrical, with a partial covering at the bottom for the purpose of retaining the fragments of core or coal (12, Fig. 50).
12. Sludgers, which are somewhat similar to the above.
13. Instrument for boring through coal, which has cross-cutters and a check valve; its use being to bring up entire sections of any seam that may be passed through (10, Fig. 50).
14. A Bèche, about 2 feet 6 inches long, and hollow for a distance of 20 inches from the bottom, the cone-shaped cavity tapering

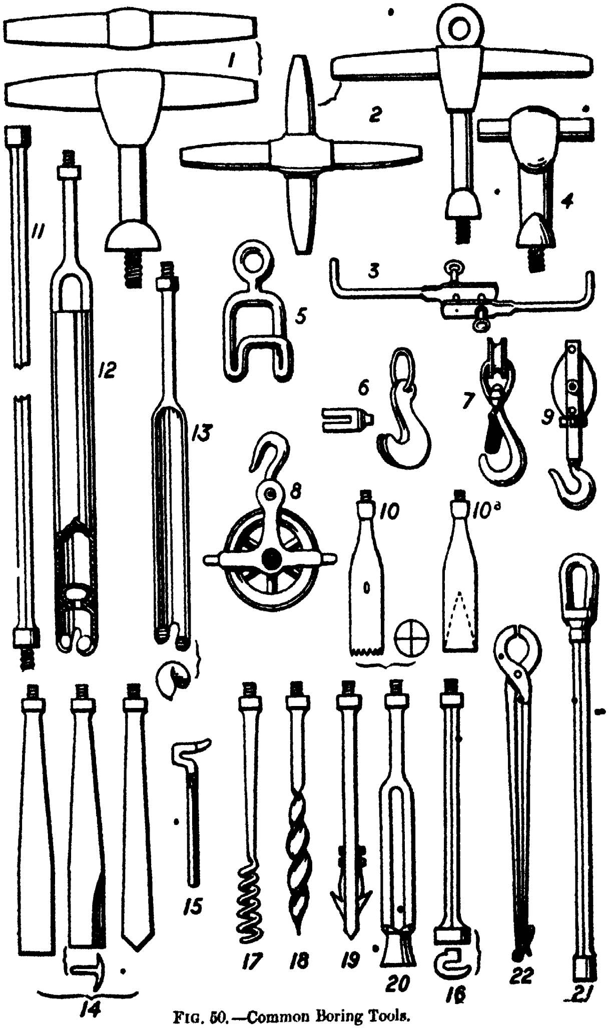


FIG. 50.—Common Boring Tools.

1, 2. Brace-head, single and double; 3. Another form of brace-head; 4. Topit; 5. Runner; 6. Lifting-dog; 7. Spring-hook; 8. Sheave; 9. Snatch-block; 10. Instrument for boring through coal, and 10a, Bèche, the latter for the recovery of lost rods; 11. Bore-rod; 12. Wimble; 13. Clay auger; 14. Three forms of chisel or bit; 15. Hand-dog or key; 16. Crow's foot (for the recovery of lost tools); 17. Spiral worm (for the recovery of lost tools); 18. Worm auger (for the recovery of lost tools); 19. Spring dart (for the recovery of lost tools); 20. Bell-box (for the recovery of lost tools); 21. Swivel rod; 22. Tongs.

from 1½ inches diameter at the bottom to a ½ inch diameter at the top (10, Fig. 50).

15. Rounders, which are used to break off any irregularities which may have been occasioned by careless boring.

Supposing a hole 500 feet in depth to be contemplated, the operation of sinking it would be as follows: The solid rock (rock-head) would be reached by a staple pit 5 to 6 feet in diameter, the sides of the same being secured by timber or brick lining. A guide tube would then be fixed in a vertical position at the point where the bore-hole is to be commenced. By sinking the staple pit the difficult boring through the soft upper beds is obviated, height also is added to the distance between surface of bore-hole and the pulley block, so that longer lengths of rods can be drawn out and unscrewed, and in this way a considerable saving of time is secured when drawing the rods for any purpose, such as changing a bit, sludging out the hole, &c., and a length of bore equal to the depth of the staple pit, which would be the costliest part of the boring, is saved, namely, what would otherwise have been the lowest length.

The diameter of the bore-hole is usually about 2½ inches. By this system holes are never put down at a less diameter than 1½ inches nor greater than 12 inches. The operation of boring is briefly this. The master-borer, or master of the shift, takes up his position at the brace-head, and while two men at the end of the lever raise and lower it, he turns the brace-head partly round, so that the cutting tool on being lowered may not strike the same place as before; when the rods fall he retains his hold of the brace-head, so that he may be able to tell by the touch when any change in the stratification takes place. When it is desired to draw the rods, the brace-head is unscrewed, the rods being meanwhile held in position by keys, a "runner" is attached to the rope and passed over the rods to the top of which the "topit" has been screwed. The rope is then wound up by the jack roll, and the rods unscrewed in the longest possible lengths. In the case of a deep hole an engine would be used for winding up the rods, and also for working them when boring. As little time as possible should be taken in sludging out a hole, and the sludger let down rapidly, its descent being checked by means of the brake in the case of deep holes of, say, 1000 feet. For such a depth about three and a half minutes would be occupied in the descent. The operation of sludging or pumping is then begun and continued for about five minutes. The time occupied in raising the sludger will be, for a 1000-feet hole, about twelve minutes.

**Rate and Cost of Boring.**—When a boring through average coal measure strata is carried out in the manner described above, the rate of progress would in the earlier stages attain perhaps 12 inches per hour, but after a depth of some 60 feet is reached the average speed will be much reduced, owing to the greater time lost in drawing and lowering the rods and sludging out the hole. The cost of boring by this method is, in the North of England, usually based on a rate of 7s. 6d. per fathom (6 feet) for the first five fathoms, with an increase of 7s. 6d. per fathom after every 5 fathoms.

Thus if $C$ = the cost of the bore-hole,
$a$ = the price of the first step,
$b$ = increase in price for each additional step,
$n$ = number of steps.

By arithmetical progression—

$$C = \frac{n}{2}\left\{2a + (n - 1)b\right\}$$

or taking the case of a bore-hole 300 feet in depth—

$$C = \frac{10}{2}\left\{37\text{s. }6\text{d.} \times 2 + (10 - 1)\ 37\text{s. }6\text{d.}\right\} = £185.$$

But it has sometimes been performed at a 4s. instead of 7s. 6d. rate per fathom, with a 4s. increase. This method of calculating the cost of bore-holes is applicable to all systems of boring, the only variants being in the price per given length and the steps.

**Boring through Clay and Sand.**—When boring through a soft stratum, such as plastic clay, for instance, great difficulty may be experienced in keeping the hole open, and it will be necessary to insert lining tubes for this purpose, which should be got into place with the greatest expedition, if possible before the clay begins to swell; success in boring in such cases is frequently entirely dependent upon rapidity of execution.

If a stratum of running sand be encountered the best way of boring through it is by means of a water jet, lining tubes being put down until the sand-bed is reached, and an inner tube fitted with a nozzle pierced laterally with a number of holes let down until the nozzle rests on the sand, the surface end being connected with a force-pump. The pressure of the water forces the sand up the annular space to the surface, the nozzle being lowered as the sand is forced up and the tube lining sunk down—pressure being kept on the tubes to force them down. When firm ground is reached the steel lining, which has a cutting edge, is driven hard into it, so as to prevent any sand or water finding their way beneath it, and so into the hole. Another method which has been tried with success, and one which has the advantage of not involving the use of any special plant, is that designed by Mr. C. B. Reynolds.[1] In the case of a bore-hole sunk by the Government of India, when proving the Warora coalfield, in the Wardah Valley, Central Provinces, the thickness of the sand penetrated was 12 or 14 feet, and was overlaid by clay.

---

[1] *Trans. Inst. M.E.*, vol. xiv. pp. 107, 110.

When the sand was pierced, the water passed up the hole into the staple pit where the men were. It was desirable that no water should be left in the hole when finished; and realising that a serious loss of time would result if there was any stoppage occasioned by having to wait for tubes, these were constructed at the mines on the Lentz method, as used at Baku,[1] and were 12½ inches in diameter. Such tubes could not stand much driving, so on reaching the running sand they were forced into it by the blows of a "monkey," as far as was deemed safe. Within them flush jointed steel tubes, 10 inches in diameter, were inserted, and driven as far as possible in advance of the larger tubes into the running sand. To the end of the column of bore rods was fixed an inverted pump-bucket of wood with leather clack-valves, and the water standing in the tubes was with Portland cement pumped downwards into the sand below, the rods being weighted with tubes to enable the bucket to force the water down. When the Portland cement had set, it was drilled through.

**Tubing a Hole.**—Should it be necessary, on account of having to pass through a bed of sand or clay, or because of a tendency of the strata penetrated to cave in, or any further reason, to line the hole or part of it with tubing, a smaller chisel, and possibly rods of a less cross section, will have to be used, after the tubing has been inserted.

It is frequently necessary to protect a hole throughout its whole length by tubing, especially if it has to be kept open for any length of time, and it may be necessary to insert the tubing as the boring proceeds, in which case, if the hole be deep, its initial diameter will be proportionately greater, as the tubing will be inserted in stages, and various sizes of chisels will have to be used, unless, indeed, some such device as that shown in Figs. 71 and

---

[1] *Petroleum and its Products*, by Sir Boverton Redwood, 1906, vol. i. p. 286.

'2, and described on p. 122, is used to bore out the hole, vhen it is possible to use the same diameter of tubing or very considerable depths, if not throughout the hole.

**. Depth to which it is Feasible to Bore with Rigid Rods.**—The depth to which it is possible to ore with a rigid column of iron rods is necessarily imited, for the jar or vibration communicated to the rods if the whole length be allowed to fall suddenly through a space of 2 or 3 feet—the usual length of stroke—and the consequent percussion of the chisel on the bottom of the hole being continuously repeated, is such as very frequently adversely affects the nature of the metal, causing breakage of the rods, unless they are made of corresponding strength, which entails great weight, and no rods will permanently withstand a continually repeated fall through the distance named, so

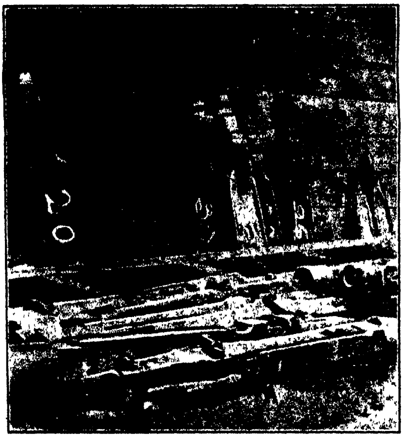


FIG. 51.—Boring Tools used at Easington Colliery Sinking, Co. Durham, in 1903.
A. Free-fall. B. Enlarging chisel.

that in practice the fall in deep holes becomes limited to a few inches. Boring by rigid iron rods is in practice, therefore, found to be practicable only up to about 1000 feet, and it is now customary in percussively boring all deep holes with rigid rods to make use of some kind of "free-fall" or other device, by which the jar to the column of rods is limited. Whatever its nature, the amount of drop to the free-fall, sliding box, or jars, must be somewhat greater than the stroke of the engine working the column of rods or the rope.

**The Free-fall.**—"Jars" were first applied to boring in 1834 by a German Government mining engineer, Von Oeynhausen. A bore-hole at Neusalz, in Germany, had been sunk to a depth of 927 feet by ordinary methods, but by applying the free-fall arrangement, which he devised for the purpose, it was found possible to carry it to a depth of 2252 feet.

(*a*) *Kind's Free-fall.*—In 1844 Kind put into use his free-fall, which replaced Von Oeynhausen's on the Continent. This consists of an arrangement whereby the cutting tool is lifted with the upstroke of the walking-beam, and released by a mechanism shown in Fig. 52 and allowed to drop. It will be seen that the slide N, which is capable of a slight up-and-down movement, is at its upper end attached to the piston D, whilst the lower end is fixed to the wedge ring K. Hence, as the rods commence to descend, the clips EE, working on the central pivots G, open, owing to the pressure of the water in the hole acting on the under side of the piston, allowing the tool and rod H to fall freely, the chisel striking the bottom of the hole, the rods following, and on reaching the top of H, the open clips or fangs pass some distance over the head I, but the moment the upward stroke is commenced and the pressure is on the upper side of the piston they close, so that the bar and wedge ring are pressed down, and the rod carrying the tool is firmly gripped. The space through which the tool falls can be made anything that is desired, being greater in the case of hard than soft rocks—as much as 10 to 18 feet when boring through the former. As will be seen from the illustration (Fig. 53), cores, if so desired, can be obtained by using a crown holding chisels—usually five or more—in place of the ordinary *trepan*. Where it is desired to bring the core to the surface, that is,

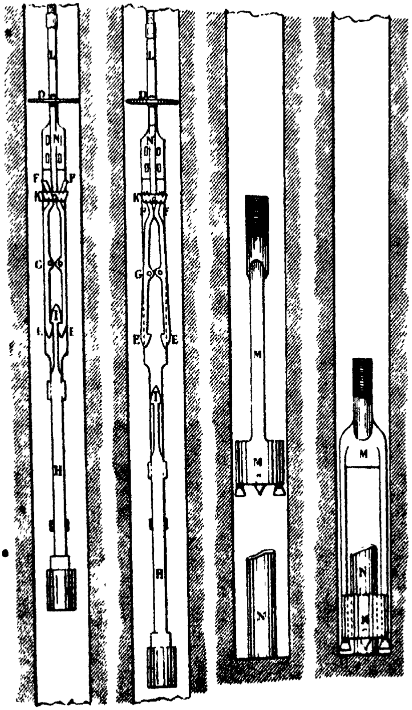


FIG. 52.—Kind's Boring Tool.

when the full length of the core chamber of the cutting apparatus has been attained, the crown is withdrawn, and the apparatus O (Fig. 53) is lowered in its stead over the core, the curved teeth PP of the same being forced outwards by an interior cylinder RR which is suspended by a cord from the surface; the teeth pressing against the core enable it to be broken off and raised to the surface. This method of boring would not be possible in

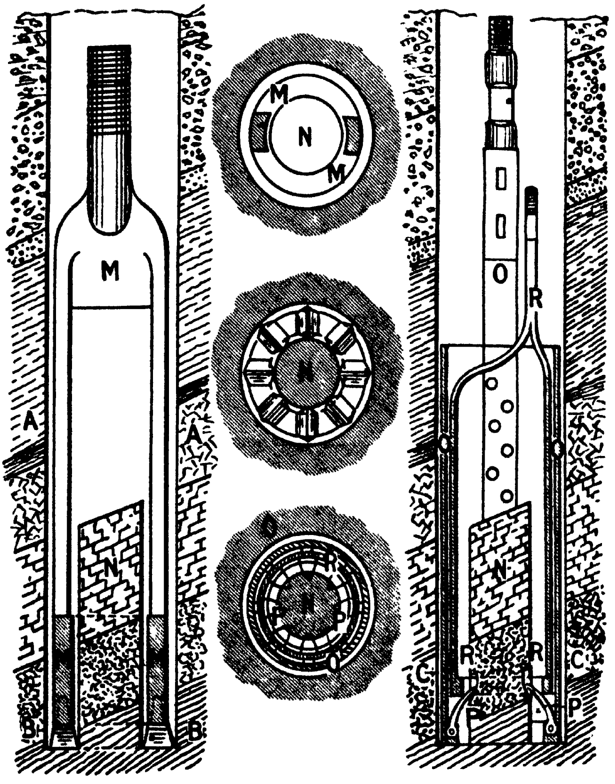


FIG. 53.—Kind's Crown-borer and Core-extractor.

a dry hole, for it is necessary that that part of the hole in which the free-fall works should be full of water, in order that the piston D may be worked. However, the majority of bore-holes do contain water.

At Kreutsberg, Moselle, in 1852, a boring 11·8 inches in diameter was put down through 890 feet of new red sandstone and coal measure rocks by the Kind system, at a cost of £806, 13s., or at an average cost of 13s. 8d. per foot over the entire depth, that is, about 8s. 8d. for the first 300 feet, 14s. 6d. the second 300 feet, and 19s. 8d. for the last 300 feet, or, roughly, an increase of 5s. 4d. per foot for each 300-feet stage. Core-boring was only resorted to when passing through a coal-seam. The hole was begun in May and finished in December.

(*b*) *Dru's Free-fall* (Fig. 54).—The tool D is composed of wrought iron, and the hook H which constitutes the head of the boring tool slides in the guide-box H, and engaging with the catch J, the tool is thereby raised on the upstroke of the "walking-beam" (or brake). The upper end of the disengaging catch J bears against an inclined plane L, and the hole O carrying the centre pin I of the catch are made oval in the vertical direction, so as to allow of a small movement in that direction. At the termination of the upstroke the rear end of the walking-beam is made to strike with some violence upon a wooden buffer block; the consequent shock occasions a slight jump of the catch, the tail of which is thrown outwards by the incline L and the hook H liberated. On the descent of the rods the catch again engages with the hook, and the rods are picked up and the process repeated. Another and slightly different arrangement of Mr. Dru's is shown in Fig. 54, in which the disengagement is effected by a rod M, and the details of which are apparent from the drawing.

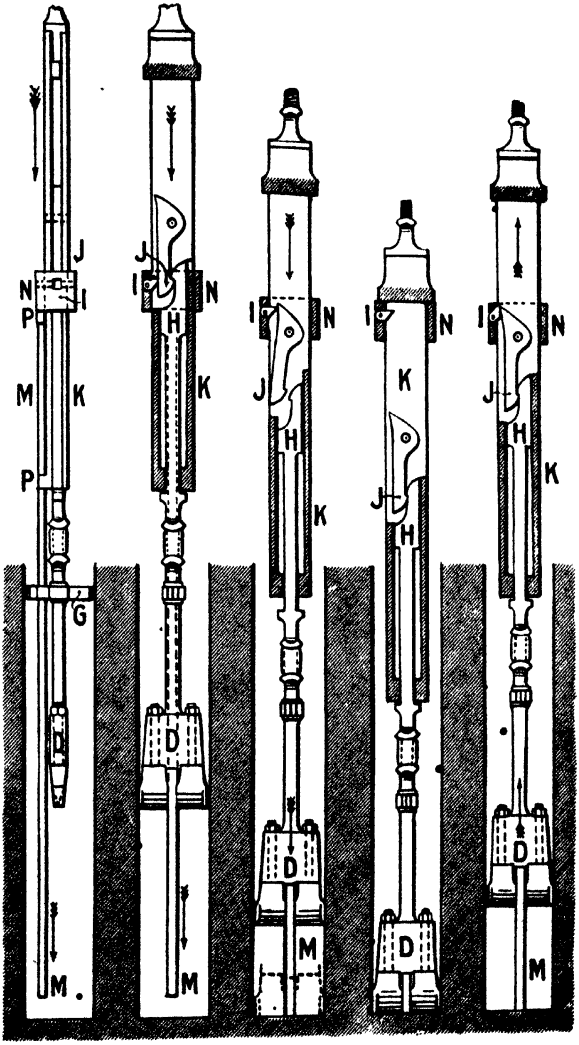


FIG. 54.—Dru's Boring Apparatus.

D is the boring-rod sliding between the vertical sides of the box K; H is the hook; J, the catch; I, the paul; M, the disengaging rod; G. the crossguides; N, the hoop; and PP are the guides.

In 1867[1] Mr. Dru was engaged in sinking a well 19 inches in diameter to a contemplated depth of 1800 feet, and another one at Butte-aux-Cailles, for supplying water to Paris, was being put down by him to a depth of from 2600 to 2900 feet, and was at that time 47 inches in diameter, and stood at a depth of 490 feet.

Considerable variation was experienced in the rate of boring when using Dru's apparatus. Some rocks were so hard that with 12,000 blows per diem from a tool weighing half a ton, and a height of fall of 19 inches, the hole only advanced 3 to 4 inches in the day. When passing through soft rock the rate of advancement was, of course, vastly greater than this.

(*c*) *Fabian's Free-fall.*—In Fabian's free-fall, the rod to which the cutting tool is attached is a tube or box, at the top of which is a pin, which, on the rods being slightly turned at the surface, engages in a slot, and this is raised by the upstroke of the walking-beam. The disengagement being effected as in the case of Dru's free-fall by shocks, and in combination therewith a turn of the rods by the driller.

Other types of free-falling apparatus, all of which have been, and still are to some extent, used, are—Zobel's, Werner's, Gaiski's, Sonntag's, Kolb's, and Kleritj's. For an account of which the reader, who is desirous of further pursuing the subject, is referred to the admirable paper by J. Clark Jefferson, in the *Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers*, vols. v. and vi.

**The Mather and Platt System of Boring.**—The special features of this system of boring are—(*a*) the mode of actuating the boring tool through the medium of a flat rope,[1] and (*b*) the peculiar construction of the boring apparatus.

---

[1] Paper by Mr. Dru on the machinery for boring artesian wells, in the *Proceedings of the Institute of Mechanical Engineers*, 1867, pp. 174–191.

In Fig. 55, on leaving the drum A, the flat rope passes under the guide pulley B, hidden from view in Fig. 55, but shown in 55A, and thence over a flanged pulley C, carried in a fork at the top of a square piston rod, worked from the vertical single-acting steam cylinder D. All the working parts being supported by a strong frame of wood or iron.

When the operation of boring is about to be commenced, the boring head E is lowered to the bottom of the hole by the rope unwinding from the drum, and the rope being then secured by the clamp F, steam is admitted into the cylinder D, which in raising the sliding pulley C gives to the rope, and hence to the boring tool, twice the stroke of the engine; on releasing the steam, the piston and its attachment drop, and the boring tool falls with considerable force on the bottom of the hole. The working of the inlet and exhaust valves is automatic through the medium of tappets, which are themselves actuated by the movement of the piston rod, and it is so arranged that the piston near the end of its down stroke is received on a cushion of steam. In this way a rapid succession of blows, usually twenty-four per minute, is struck by the tool at the bottom of the hole. By shifting the tappets, the length of stroke of the piston can be varied from 1 to 8 feet. When necessary to clean out the hole the clamp F is released, the boring tool wound up and replaced by the shell pump, which is lowered into the hole, and by raising and lowering it about three times at the bottom of the hole, by means of the reversing gear of the winding-engine, the debris is removed. The boring tool is shown in Fig. 56, and consists of a slot head B, into which are inserted steel

---

[1] Messrs. Mather & Platt have in operation also a round rope system of boring.

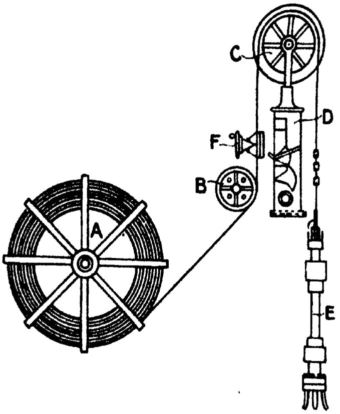


FIG. 55A.

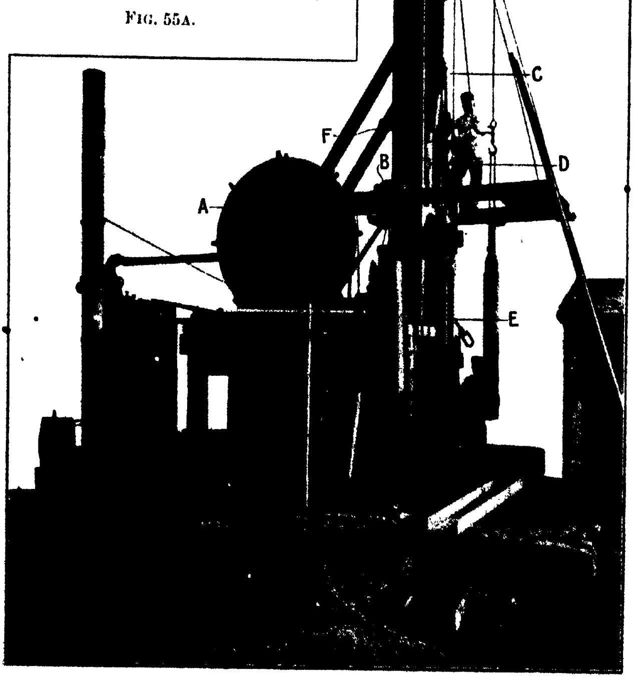


FIG. 55.—Mather & Platt Flat Rope Boring Apparatus.
FIG. 55A.—Diagrammatic explanation of the same.

teeth or chisels C; the wrought iron bar which carries this head is guided in the hole by the guides A A. At the top of the bar are secured two collars, E and E; the upper face of the lower collar and the lower face of the upper collar have deep ratchet teeth, set in line; a deep bush F which has corresponding ratchet teeth on both faces slides freely on the bar between these collars, the top teeth being set half a tooth in advance of the lower teeth. This bush has attached to it the stirrup G hanging from the flat hempen rope. On the boring bar falling and striking a blow, the bush disengages from the teeth on the upper collar, and falls upon those of the lower collar, and so is twisted through a distance of half a tooth. On the raising of the bar the bush engages again with the teeth of the upper collar, and is again twisted to the extent of half a

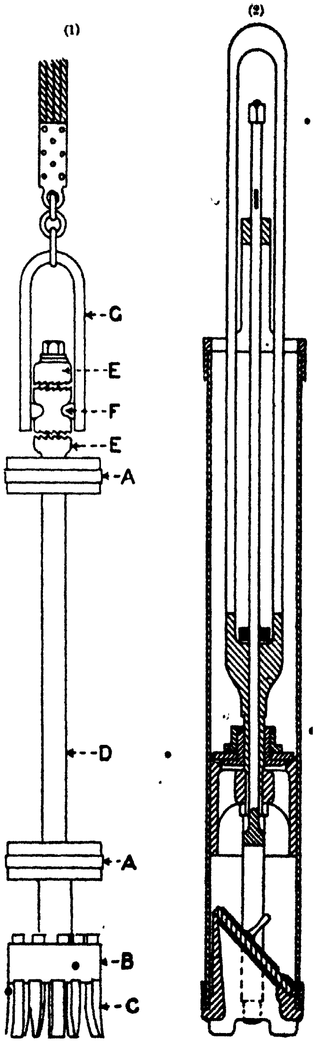


FIG. 56.—(1) Boring tool. (2) Sludger.

tooth. That is to say, a twist to the extent of half a tooth is given to the rope, which is untwisted again during the lifting of the bar, consequently a constant rotating movement is imparted between the blows to the cutting crown, and each chisel strikes in a new spot on each successive blow.

One of the earliest holes put down by this method was in 1861 at Middlesbrough, for Messrs. Bolckow, Vaughan and Co., Ltd. The hole was 18 inches in diameter and 1312 feet deep, and penetrates the sandstones (about 900 feet), marls, and gypsum beds of the new red sandstone. The first 600 feet occupied 100 days; the total time occupied by the boring was 540 days, but 150 of them were engaged in pumping water for test purposes and by other stoppages. When penetrating the sandstone the rate of boring was 13 feet in 13 hours, and when the depth of the hole was upwards of 1110 feet the progress amounted to only 3¼ feet per 13 hours.

Quite recently, in Poland, it was used to bore a hole, 33 inches in diameter at the top and 16 inches at the bottom, to a depth of 2280 feet; and at the time of writing is being used near Burnley, in Lancashire.

Good cores are obtained by this method, and the framework of the machine occupies little space.

# CHAPTER V

## LATER DEVELOPMENTS IN BORING

It has been shown that the first improvements in boring were directed towards relieving the rods of the vibration, consequent on the falling of the great weight. In the so-called "Canadian" system of boring this is secured by the substitution of wooden rods instead of iron or steel, and differs from the "American" rope drilling process, presently to be described (p. 102), in the use of ash-poles[1] in place of a hempen rope for carrying the boring tools.

Mr. Nelson Boyd, in an interesting paper read before the Society of Engineers in May 1894, in which he discussed the method of boring, supplies data which enables us to compare it with others in point of economy and efficiency.

In boring a deep well in Galicia (Austria), the time occupied in drawing up and letting down the rods when it was necessary to clean out the hole (the details of which were noted by Mr. Nelson Boyd himself, the well being, at the time of the observation, 1542 feet deep) was as follows:—

| | |
|---|---|
| Drawing rods . . . . . . . . . | 25 minutes. |
| Letting down the sand-pump by means of the rods | 14 ,, |
| Drawing up the sand-pump . . . . . . | 24 ,, |
| Changing the chisel . . . . . . . | 3 ,, |
| Letting down the chisel . . . . . . | 14 ,, |
| Connecting the beam . . . . . . . | 5 ,, |
| | 85 minutes. |

---

[1] Wooden rods are also sometimes used on the Continent, fashioned of straight-grained pine, 2¼, 3, or 4 inches square, and 33 to 39 feet long, jointed in the same way as iron rods, viz. a socket at the bottom and male screw at the top, these iron pieces being fixed to the rods by means of forks and fastened with bolts. See Callon's *Lectures on Mining*, vol. i. p. 100.

Whereas a similar operation performed by rope in an oil-well in Pennsylvania, 1600 feet in depth, occupied about twenty minutes, so that in deep holes the advantage in this respect lies with the "American" as compared with the "Canadian" system. Though in a shallow hole the "Canadian" may be the better method of boring, by the "American" system it is possible to bore a hole of less diameter than by wooden rods; on the other hand, however, it is more difficult to preserve verticality when using a rope, especially when the strata penetrated are much inclined.

The "Canadian" system has been largely used for boring oil wells, and the cost per foot, according to Mr. Nelson Boyd, varies between 16s. and 30s. a foot, but he puts the average cost at about £1 per foot.

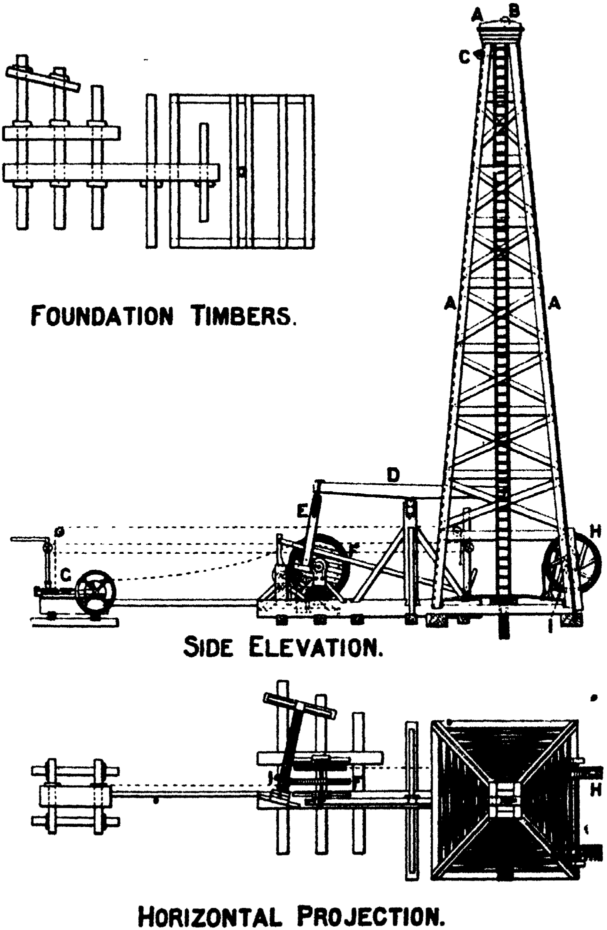
**The American Rope Drilling Method.**[1]—The "Rig," Fig. 57, as it is called in America, consists of a derrick, band-wheel, bull-wheel, sand-pump reel, sampson post, walking-beam, and engine-house.

*The Derrick*, A, made of hemlock (pine wood), is somewhat pyramidal in form, composed of four uprights resting on hewn oak or stone sills, and held in position by the necessary ties and diagonal braces, generally about 70 feet high and 20 feet square at base. This derrick carries two sheaves, the crown-pulley, B, and the sand-pump reel. The object of its great height will be readily understood when the pump-drawing operation is described.

*The Walking-beam*, D, is the instrument which communicates the perpendicular up-and-down motion to the rope which carries the drilling tools, and this is put in motion by the "pitman," E, which is a kind of connecting-rod attached to the crank of the "band-wheel," F, the

---

[1] See a description of this method by the author, in his paper, "The Salt Deposit of South Durham and Yorkshire," *Trans. Brit. Soc. Mining Students*, vol. x. pp. 92, 103.


FOUNDATION TIMBERS.

SIDE ELEVATION.

HORIZONTAL PROJECTION.

FIG. 57.—The "Rig" of the American Rope Drill.

"band-wheel" being driven by a band from off a wheel worked direct by the engine, G.

*The "Bull-wheels,"* H, are also made of wood. The total length of the oak shaft is from 10½ to 12 feet and its diameter 13 inches, the diameter of the wheels being 6½ to 7 feet.

*The Brake,* I, is an iron strap applied under the wheel as shown.

*The "Band-wheel"* is fashioned of fine hard wood, and is carefully planed. It is about 7 feet in diameter. The grooves of the rope-pulleys on band and bull wheels are made of hard wood. The "sand-pump reel" friction pulley, J, has been shown by experience to be the most awkward part of the whole "rig."

The ordinary drilling tools, which are shown in Fig. 58, comprise a "sinker bar" (*a*), which is screwed into the "rope-socket" (*d*), and the "jars" (*c*), which are two flat links. Their function is to give the auger-stem (*b*) and "bit" (*f* and *f′*) a decided jar on the upstroke, and to loosen the bit (or chisel) in case it should become wedged fast in the hole. The "sinker-bar" is added to give the required force to the upward jar. All these tools screw into one another, as shown.

Before drilling is commenced, wrought iron tubes of 20-feet lengths and ⅜-inch thick, which screw into one another, and of a diameter suitable to the bore-hole about to be put down, are driven through the soft upper beds of clay and sand, supposing such to exist. These pipes (*n* and *m*, Fig. 58) are termed "conductors" or "drive-pipes." Their object is to protect the sides of the hole from the clay and sand, which would otherwise completely choke it up. The first one is driven so far down, a second screwed on top of it and driven down, and so on until the solid rock is reached.

Upper soft or alluvial formations (say, 60 feet) cannot be drilled in the ordinary way, so that the following method, called "spudding," has to be resorted to. This

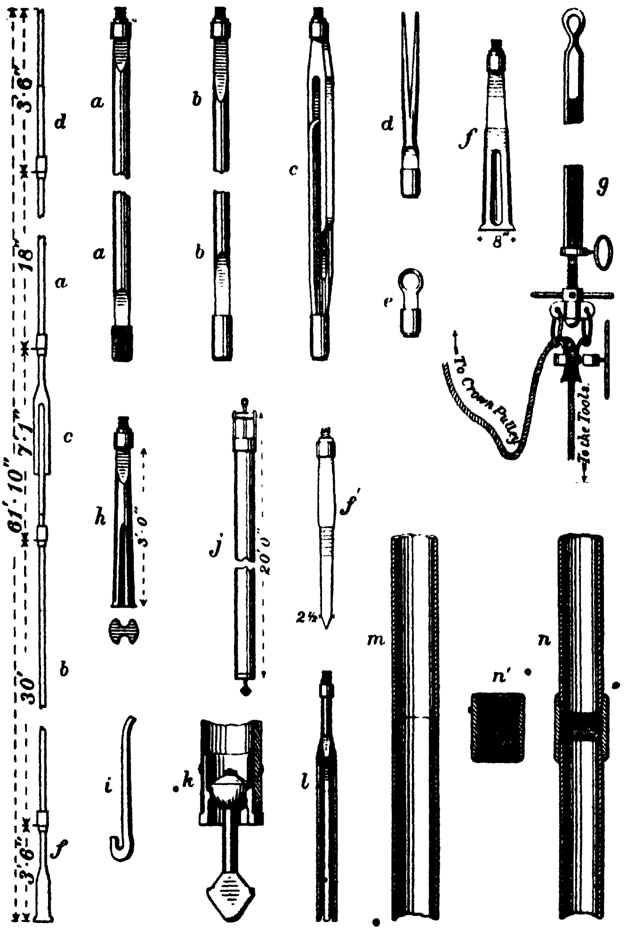


FIG. 58.—Some of the Tools and other Appliances used in American Rope Drilling.

consists of attaching the auger-stem and bit by the rope socket to a short piece of cable, about 160 feet long, the other end of which is passed round the crown-pulley and down to the bull-wheel, a few turns being passed round the bull-wheel shaft. The engine is then started. One of the drillers stands near the bull-wheel with the loose end of the cable in his hands; a slight pull on this tightens the loose coils on the bull-wheel shaft, which is rapidly revolving; the tools are raised, the rope is immediately slackened, the tools drop, another slight pull is given, and so on until a sufficient depth is attained to enable the walking-beam to come into operation. The conductor pipes are driven through the soft beds, say, clay and sand, with a wooden "mall" made of oak, 20 feet long by 14 inches square, which is raised and lowered in the same manner in which the tools are handled in "spudding."

Firm ground having been reached, drilling proper is commenced. The drilling cable, of 6 inches untarred manila rope, is passed over the crown-pulley and coiled upon the bull-wheel shaft, and the other end fixed into the rope socket. The tools are then screwed up, and lowered into the hole by the bull-wheel brake. The walking-beam is connected with the band-wheel by slipping the pitman on to the wrist pin and driving up the key, and what is called the " temper-screw " (*g*, Fig. 58) is suspended by a hook to the walking-beam. The temper-screw, which is perhaps the most ingenious of all the clever appliances connected with this boring apparatus, connects the rope and the walking-beam, its purpose being the lowering of the tools as the drilling progresses, which is done by letting out the screw. After drilling 4 feet, it is necessary to withdraw and re-clamp the rope.

As the tools rise and fall they are constantly rotated by hand by means of a short lever inserted in the rings of the temper-screw. The driller is enabled to discern, by means of the vibrations communicated through the rope from the jars, how the tools are working. When the temper-screw is run out the tools are withdrawn. To do this the bull-wheel rope is thrown into gear and the bull-wheel brake applied, the engine being stopped when all the slack rope is wound up. The clamps are then loosened and the pitman thrown off, the walking-beam put out of the way, and the rope with the tools run up. The engine is stopped and the bull-rope thrown off, the tools being then pushed aside out of the way, and the sand-pump, which is always attached to the sand-pump wheel, is run up and down four or five times by means of the friction gear and brake block shown on the plan. When the sediment is cleaned out of the hole the tools are again lowered, controlled by the bull-wheel brake, the walking-beam connection made, the temper-screw clamped to the rope, and boring recommenced.

Sometimes the conductors are driven too far, and as pipes will not penetrate hard rock become contorted and buckle up. In order to straighten them a tool like a plumber's soldering iron, called a round reamer, is attached to the rope socket, and rapidly let down by the rope, so that it falls with considerable force on the contorted pipe or pipes. It is also used for rounding the bore-hole should any little irregularities be occasioned by careless boring. There are many tools which come into play in connection with this system of boring, such as the "spon" used for enlarging the hole around a fast tool, several other kinds of tools for enlarging the hole, a catch for clutching a broken rope, a tapering iron tube for bringing up unfastened tools, a tool for cutting the rope in the hole supposing the tools are fast, and many others.

Wire rope has not been found to answer for drilling purposes, as it is not pliable enough to wind on the shaft of the bull-wheel, and to increase the diameter of the shaft would be to lose power.

A set of tools in America costs about £80 for a 5½-inch diameter hole, and weighs about 18 cwt. They are made in the stem of 2½ to 3 inches round iron, boxes and pins being of Norway iron. The bits and reamers are also made of Norway iron, with large steel tips. The jars are composed entirely of Norway iron.

The following are the various lengths and weights of a set of drilling tools:—

| | | | | | |
|---|---|---|---|---|---|
| Rope socket, | weighs | 80 lbs. | and is | 3 ft. 6 in. | long. |
| Sinker bar, 3½ in. | „ | 540 lbs. | „ | 18 ft. | „ |
| Jars, 5½ in. | „ | 320 lbs. | „ | 7 ft. 4 in. | „ |
| Auger-stem, 3½ ins. | „ | 1020 lbs. | „ | 30 ft. | „ |
| Bit, 5½ in. | „ | 140 lbs. | „ | 3 ft. 3 in. | „ |
| Total . | . | 2100 lbs. | | 62 ft. 1 in. | „ |

The round reamer for a 5½-inch hole weighs 140 lbs. The other tools and apparatus shown are, the ring socket (*c*), key or wrench (*i*), sand-pump (*j* and *k*), three-wing rope grab (*l*), and tubing with common coupling (*n*).

As to the rate of boring, 100 feet per diem of twenty-four hours has been done through new red sandstone at Haverton Hill, near Middlesbrough, but the rate was slower when boring through shale or marl.

The cost of drilling was about 8s. per foot, calculated over a 1000-feet bore-hole at Haverton Hill.

To bore and line with tubing a hole 950 feet deep in the salt district, Haverton Hill, South Durham, the diameter of the hole being 8 inches, took three weeks, and cost £1950 (lining with ¼-inch steel tubes), included in the cost being the price of the engine hole plant, &c., this being the average calculated over several holes.[1]

Among the advantages of this system may be cited the fact that a hole can be cleared of obstruction rapidly and easily in the case of oil or salt well, and that it is not necessary to remove the derrick and accompaniments, as they are used for pumping the oil or brine.

This method has been used for boring for oil, salt, gas, water, and coal. In fact, during ten years, 1878-1888, no less than 30,000 oil-wells were put down by it, one hole in Wisconsin, U.S., being sunk to over 3700 feet in search of mineral gas.

**The Keystone Core Drill** is perhaps the most recent development of the American rope-drilling process, and has this advantage, that water flushing is not necessary to its application, and as the core is protected by a non-revolving core barrel which continuously slips down over it as it is formed, preventing it from being broken and washed away, it is possible to obtain good cores when penetrating soft rocks. It is usual, however, to bore to the coal with an ordinary bit, then removing the bit and stem (but retaining the jars) to put on the core drill attachment in their place.

The core drill and core barrel are shown in Fig. 59. It will be observed that the core barrel projects out of

---

[1] A remarkable record of rapid drilling, for the details of which I am indebted to Mr. C. H. Matthews, was that done at the No. 3 oil-well of the California and New York Oil Company, Coalinga, California. The "rig" was set up on December 12, 1905, and the well completed to a depth of 1473 feet by February 24, 1906. The diameters of the casing was as follows:—

| | |
|---|---|
| For 600 feet | 12·5 inches. |
| For 900 „ | 10 „ |
| For 1240 „ | 8 „ |
| For 14 „ | 6 „ |

The 10-inch casing was afterwards drawn out and used at the No. 4 hole.

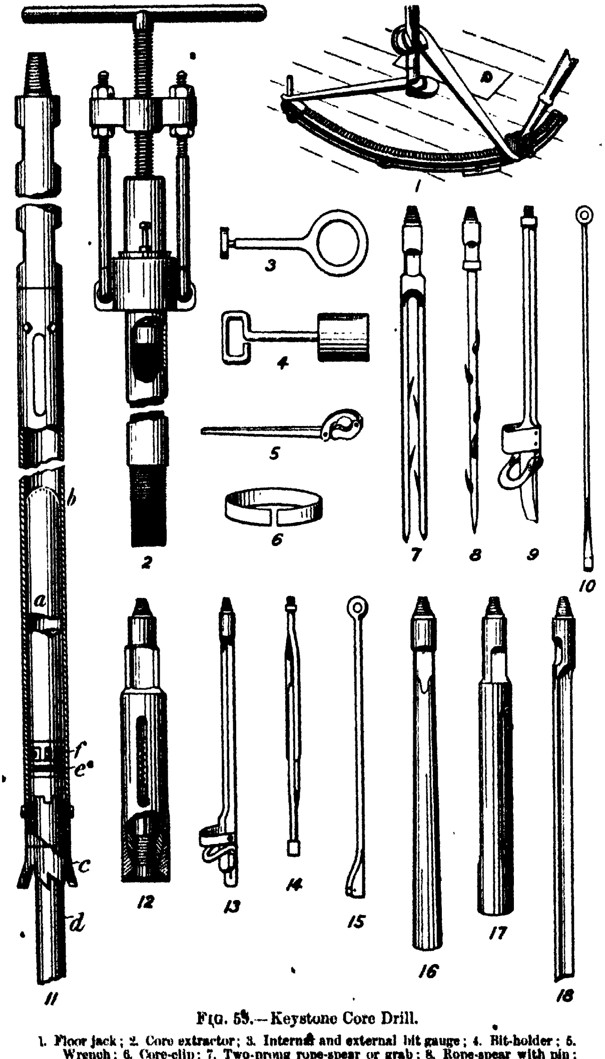


FIG. 59.—Keystone Core Drill.

1. Floor jack; 2. Core extractor; 3. Internal and external bit gauge; 4. Bit-holder; 5. Wrench; 6. Core-clip; 7. Two-prong rope-spear or grab; 8. Rope-spear with pin; 9. Horse-shoe knife for cutting the rope when the tools get fast in the bore-hole and the rope is not broken. The jars must be used with it and connected with the piping to the top of the hole; 10. Sinker used with horse-shoe knife and rope knife jars; 11. Keystone core drill; 12. Side slot combination socket for getting hold of a rope-socket or a pin; 13. Horse-shoe trip rope-knife; 14. Jars; 15. Solid jar bumper, for striking on top of rope-socket when tools are fast in a hole; 16. Horn-socket for driving over an iron tool of uncertain size; 17. Slip-socket used for catching of a rope-socket or the round iron of the stem if broken; 18. Spud for cutting out the hole round a fast tool to loosen it.

the hollow stem and below the cutter for about 4 feet, that length representing the longest core that can be taken at one time. The core barrel is prevented from being lifted on the upstroke of the cutter by a heavy steel "knocking head" *a*, which fits loosely in the hollow stem *b*, and though it may have a tendency to turn about in unison with the stem and the cutter *c*, it cannot communicate this tendency to the core barrel *d*, as between them is introduced a ball-bearing swivel joint *e*, which effectually prevents the core being twisted. The anti-friction rollers *f* at this swivelled joint steady the weighing bar centrally within the hollow stem, and prevent the latter from lifting the core barrel by friction. The annular cutter *c* is made of fine crucible steel. Two cutters and two bit gauges (Fig. 59) are furnished with the outfit, one for the outside and the other for the four inside teeth.

The speed of drilling with this apparatus is said to be, for ten hours a day—

| | |
|---|---|
| For trap rock, granite, porphyry, &c. | 8 to 15 feet per diem. |
| Soapstones, water-shales, &c. . . | 70 to 80 „ „ |

The entire staff consists of two men; and the consumption of material amounts to about 600 lbs. of coal, or one cord of wood, and eight to ten barrels of water per diem. The cost of a complete tool outfit is $200 (£41, 13s. 4d.), and includes the following (see Fig. 59):—

One 4½-inch by 7-foot vacuum sand-pump.
One sub top stem.
One hollow stem.
Two cutters.
Two core barrels.
Two extra core grips.
One swivel head and weight bar.
One core extractor.
Three wooden pushers.
Five core receivers.
One internal and external bit gauge.
One bit holder.
Two large wrenches.
One small wrench.

**The Employment of Water Current, and Recent Improvements in Boring.**—A great transformation has been produced during the last twenty years in the technique of boring, for though the employment of the water current invented by Fauvelle goes back to 1845, it is only of late years that the systems of boring in which this mode of cleaning bore-holes is used, have been employed to great extent, and if they have not completely supplanted the old processes, they have at least made them lose much of their importance.[1]

The greater depth to which it is necessary to go in search for minerals necessitating greater rapidity—in the interests of economy—and sureness in execution, has done much to improve the appliances in this department of mining, especially on the Continent of Europe, from which of late years many important improvements have emanated. The Prussian Mining Law of 1865 no doubt gave a considerable impulse to invention, in the direction of accelerating boring operations, for by this law was granted to the first discoverer of a mineral formation the sole right of working the deposit.

The supercession of the old dry method of boring by the water-flush, the introduction (from England) of the diamond process, the invention of the rapid percussion systems with rigid rods and compensating springs, which have so largely replaced the free-fall apparatus, and, quite lately, the introduction of the hydraulic ram process, covers the history of modern boring processes.

What is characteristic of all modern processes of boring is the employment of a continual water current, which, pumped down to the bottom of the hole, rises to the surface again, carrying with it, owing to its rapidity, the sediment produced by the boring, and so contributes greatly to the augmentation of the rapidity of boring, as expressed by the ratio of the total length of a hole to the time necessary to its entire execution. By the older methods of boring, the chisel exercises in the earlier stages the full effect of its blow; but this efficiency gradually decreases, as on the bottom of the hole there is formed a more or less resisting and elastic bed of sediment hindering the progress of the tool. When the effect of the tool becomes very weak the hole has to be cleaned out, necessitating a considerable loss in boring time.

---

[1] For an able review of this subject the reader is referred to an article entitled *Les Procédés Modernes de Sondage*, by M. Armand Renier, in the *Revue Universelle des Mines, de la Métallurgie*, &c., January 1904.

It is in this respect that the great advantage in the use of a current of water is evidenced, for as it continually washes away the sediment, the boring tool, percussive or rotary, is being always applied on a bare rock surface —that is, with its greatest useful effect. There is another advantage, not at first perhaps apparent, which is secured by the use of this flushing current important where boring percussively—the number of strokes per minute can be reduced, and it is possible to bore to a great depth without cessation.

It is about twenty-two years since Baron Van Ertborn succeeded in boring 246 feet in thirty hours, without once drawing the trepan (chisel); but owing to recent improvements this figure has since been largely exceeded. In 1902 the *Société Minière et de forage Bonne-Espèrence* deepened by 369·8 feet in twenty-four hours the boring of Meeswijck, which passed through alternating sands and clays, and the *International Bohrgesellschaft* (Raky) deepened by 727·22 feet the boring of the No. 26 Bolderberg under the same conditions. These are, of course, very exceptional results, even for such soft strata as those penetrated.

Another fact that contributes to the rapidity of execution is that the use of the water current allows of a reduction in the tubing operation, as it washes away the fallings-in from the sides of the hole, which are sometimes due to the pressure of the rock, and are sometimes caused by the beating of the rods against the side. In the older methods it was frequently necessary to carry the tubing well down as the hole proceeded, in order to prevent the latter being blocked up at the bottom. Another advantage secured—an indirect one—is the increased gain in the length of one section of hole, which in a given depth means that one is enabled to commence operations with a less diameter of hole than would be possible if the tubing had to quickly follow the boring, and so, in most instances, allows of the search for minerals being carried out to a greater depth than would be practicable by the older methods of procedure.

There is also greater facility of supervision, and the drill superintendent is enabled to judge far more frequently, from the character of the constant outflow of sediment, the nature of the strata that he is traversing than is possible when "dry-boring."

Against the advantages has to be put the disadvantage—in some cases great—of having to procure a sufficiency of water. The writer has found this a matter of considerable difficulty when using a diamond drill in some parts of South Africa, and one has in such cases to conserve the supply as much as possible by using the water over and over again, clarifying it by making use of settling ponds and decantation.

If, in boring, a "water-sheet"—as in the case of artesian wells—is encountered, a considerable spouting of water will ensue, and the hole be spontaneously cleared if the outflow is sufficiently strong, though in this case it might be necessary to put in tubing without much loss of time, as otherwise, though rarely, subsidence of the hole may take place after some time.

Where the piezometrical level of a "water-sheet" is lower than that of the ground being bored through, the injected water is more or less absorbed, and if cracks or joints in the strata are at all pronounced, a total loss will ensue, no water returning to the surface. The writer has experienced this difficulty, and overcome the same after a time by passing clay down the hollow rods with the injected water current, without having to resort to the tubing out of the hole.

There are two ways in which the water current is made use of:—

(1) The first and most ordinary one, and that to which the above remarks refer, is where the current is injected through the tubes constituting the boring rods, and returns to the surface by way of the annular space between the rods and the side of the hole (see Fig. 60, which represents a percussive borer).

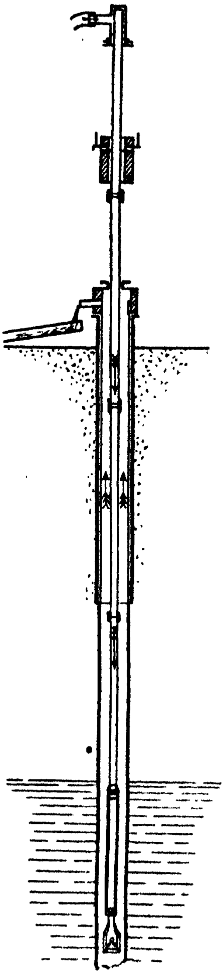


FIG. 60.—Percussive Drilling with Water-flushing.

(2) The second method is that in which the direction

of the current is reversed (Fig. 68), that is to say, the return current is through the interior of the boring tubes, and thus, as will be presently shown, has, in some cases, the advantage of greater velocity, and is enabled to carry to the surface sediment of greater density or volume than when used in the normal way.

All boring arrangements using water-flushing are composed of—

*a*. The driving apparatus.
*b*. The pump and connecting pipes.
*c*. The rods and their connection with the lengthening arrangement.
*d*. The top of the tubing.
*e*. The injection water and exterior circuit, decanting basins, &c.

(*a*) The driving apparatus will be considered under each separate method of boring.

The pump is either a lifting or forcing one. Plunger-ram pumps being most frequently used when the feed water is muddy.

(*b*) The outflow from the pump varies with the diameter of the hole. In great borings it reaches 50 to 100 gallons, and sometimes even exceeds 130 gallons, per minute.

The pumping pressure varies with the depth and the diameter of the hole and nature of the sediment—from 75 to 225 lbs. per square inch, in the majority of cases, at about 2000 feet in depth, and as high as 375 lbs. per square inch at from 3000 to 3300 feet.[1] It is much less (30 to 90 lbs. per square inch) in the reversed current method. In any case a very large margin of pumping power should be allowed for as an emergency—falling in of strata, jamming of the boring tool, &c., may at any time arise; in fact, in borings of any magnitude, one would be well advised in having a double pumping installation. If worked by steam the pump should, in case of accident to the latter, be supplied independently of the driving gear.

---

[1] *Vide* M. Renier in the *Revue Universelle des Mines* (January 1904), p. 47.

*The Coupling Arrangement.*—The connection of the pump to the bore-rods is through the medium of flexible indiarubber hose, so as to allow of the movement of the rods, or, in the case of the reversed current, of the tubing. This part of the mechanism carries a metallic pressure gauge, and sometimes a safety-valve. By the former any obstruction in the hole retarding the circuit of the current is indicated, and the latter prevents an abnormal and dangerous pressure being reached, though the indiarubber hose is in itself a safety-valve.

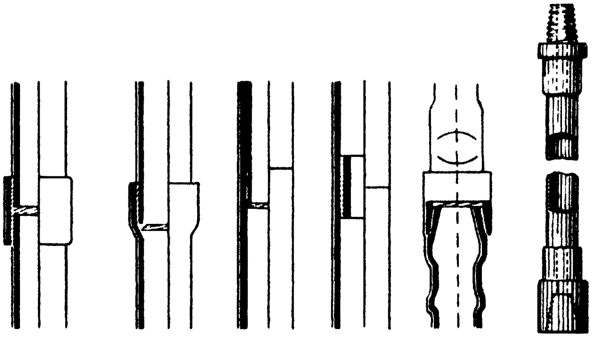


Fig. 61. Fig. 62. Fig. 63. Fig. 64. Fig. 65. Fig. 66.

Types of Hollow Boring Rods.

(*c*) *The Rods.*—The rods are made of tubes drawn together by screwed couplings (see Figs. 61, 62, 63, 64). The inner wall, it will be observed, is smooth in most cases, so as to offer as little obstruction as possible to the injected current. Figs. 65 and 66 represent more complicated and expensive types, but they allow of the use of a simple screwing-up key, the shoulder preventing any slipping of the same, when fastening or unfastening the rods; the use of the conical screw greatly expedites the process of joining up the rods.

In very deep borings the rods have to be in sets of different diameters, thus diameters of 2, 1½, and 1¼ inch is a common series for use in a deep hole with interior junction of 1½ and ¼ inch.

The length of rods on the Continent is usually 5 metres (16 feet 4¾ inches).

*Junction of Rods to Water Pipe.*—The connecting medium of the rods with the hose must be such as will allow of the vertical movement and rotation of the rods; the indiarubber hose allows of the vertical movement, and the swivel of the rotation.

Fig. 67 illustrates one of the best types of swivel in use, which was designed by Verbunt and is known as the "Hollander." It serves also as the suspension medium of the rods to the cable hook. The fixed part comprises two pieces, the curved part of the tube TT bound to the indiarubber hose CC, and the vertical part passing into a stuffing-box, carried by the movable part XX screwed to the top of the last rod. The second fixed part being the ring AA suspended from the hook by two stirrup straps, and acting as a support for the movable part through the medium of a box of ball-bearings. Two rings, E and E, forming the nut and jamb-nut of the screw, secure a perfect connection of the ring A with the movable part XX. When the apparatus does not require to be hung the piece A is omitted.

(*d*) *The Head of the Tubing.*—In the case of the normal current the head of the tubing does not call for particular mention. A plate with a central hole for the rods covers the top of the tubing, the diameter of the central hole being slightly greater than the coupling piece at the junction of the rods, the object being to prevent the fall of material into the hole. A lateral overflow is provided for directing the flow of the water current and slimes to the decanting ponds.

When it is a case of using the reversed current the top of the tubing is sealed, the rods passing through the seal by means of a stuffing-box (see Fig. 68).

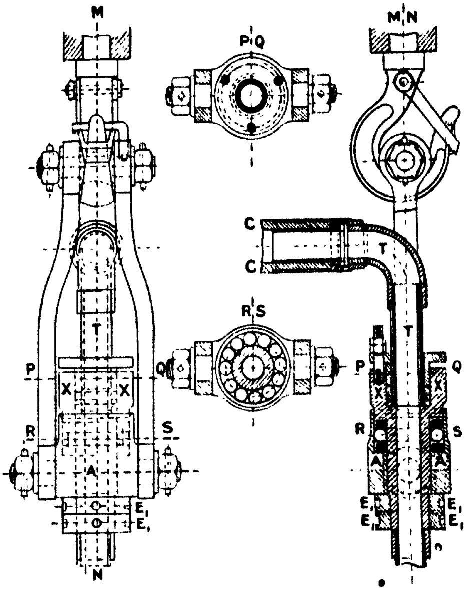


FIG. 67.—Verbunt's Water Swivel.

(*e*) *The Injection Water.*—So long as it is not acidulated or ferruginous, the quality of the injection water is generally of little importance, except that it is advisable that it should be clear when it is a case of putting down an exploratory hole, in order that it may be possible to determine from the colour of the out-flowing current the kind of rock being bored through. When prospecting soluble rocks, such as those containing potassium or soda, it would be necessary to use water saturated with chloride of magnesium or chloride of lime in order to obtain proper samples of the rock.

**Boring by Dredging.**[1]—This method is only applicable to incoherent strata, such as sand and gravels. Sometimes the direction of the current is normal, as in the Danish method,[2] but more often it is reversed, the rods being terminated by an auger which accentuates the action of the current of water. The arrangement is shown diagrammatically in Fig. 68.

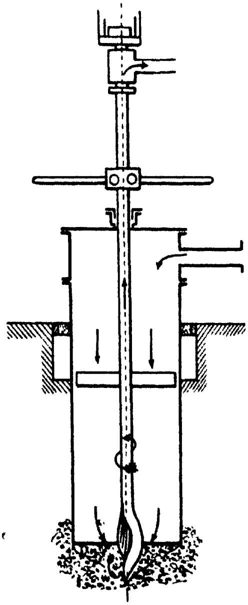


FIG. 68.—Boring by Dredging.

After the excavation of a shallow shaft, the first course of tubing is put in and provided with guides to assure the vertical direction of its descent. This tubing, smooth on the outside, carries at the lower end a cutting shoe, the upper end being covered by a special cap. The rods, which are terminated by an auger and suspended by a cable, attached to a winch through the medium of a swivel, are rotated by a key or brace-head.

The water current, which has a considerable outflow force, is engulfed into the auger carrying with it the gravels and sands, and so causing the formation of a cone-shaped cavity at the bottom of the hole, the walls of which are continually falling in, and allow of the continual descent of the tubing: occasionally, the action of the current is accentuated by turning the boring tool. Force is applied to the tubing if it sticks in its descent, but if it cannot be moved down it will be necessary to put in a column of smaller diameter within it.

---

[1] This is the "Sondes a dragage" of the French, and the "Spulschappe" of the German borers.

[2] This method only differs from that here described in the omission of the auger and the difference in the direction of the current.

The process is slow, and often carries with it a quick reduction of the diameter of the hole; nevertheless it has often been successfully resorted to when penetrating upper beds of gravel or of loose substance containing fragments of rocks, which a boring chisel would only pulverise with great difficulty.

### Boring by Percussion

**The Boring Chisel.**—There are two kinds of boring tool used in the systems of percussion drilling, the chisel and the crown; the former, usually made of a single blade, is by far the most generally used. The injected water escapes by two channels and flows over the cheeks of the chisel at a certain height above the cutting edge, or more rarely in the blade edge itself (see C, Fig. 69), though this seems a dangerous point for the outflow, owing to the ease with which the exit might be obstructed. In fissured rocks a cross-bladed tool is used.

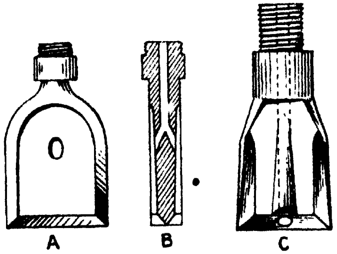


FIG. 69.—Boring Chisels with Water Channels.

**The Cyclone Drill Company of America** have an ingenious type of bit in use with their percussive drilling apparatus. On either side of the shank of the bit is drilled a hole intersecting with one drilled down through the centre, and directly on top of the bit is placed a steel washer and ball, forming a valve, so that the action of rods and valve constitute a pump, the chips of rock as they are cut being drawn into the bit and passed out through the discharge hose at the top, and the bottom of the hole kept clean (see Fig. 70).

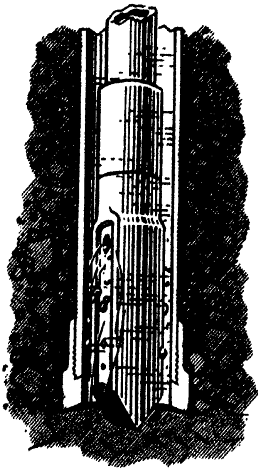


FIG. 70.—Cyclone Percussive Bit.

**Fauck's Boring Apparatus.**—It is the practice of some contractors to closely follow up the boring with the tubing in order to prevent the possible falling in of the sides, but if the enlarging of the hole for this purpose is made a separate operation it brings with it a considerable increase in the time occupied in the completion of the boring. For this reason it is preferable to put the enlarging apparatus at a certain height above the main penetrating chisel. Fig. 71 shows Fauck's[1] eccentric trepan, the use of which allows of doing without a separate enlarging process. The tool possesses a stepped blade of a size slightly inferior to the interior diameter of the tubing, and a presser with a spring projects the blade, giving it an eccentric position,

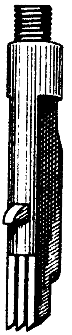


FIG. 71. Fauck's Trepan.

---

[1] The two Austrian brothers, Herren Albert and Moritz Fauck, have done much of recent years towards perfecting boring apparatus, and have patented several designs of driving mechanism and boring chisels. The arrangements described above are these which, in the opinion of the author, are the most effective.

so that the diameter of the bore is slightly in excess of the exterior diameter of the tubing. It is, however, better, if it is resolved to follow up the boring directly with the tubing, to use the crown borer and reversed current (Fig. 72). This tubular bit is composed of three parts, namely, the bit proper ($k$), the reamer carrier ($k_1$), and the connecting piece ($k_2$) to be screwed into the tubular rod. The bit is provided with radial cutting edges ($n$) and ($n'$) formed on its face, the diametrically opposite edges (Fig. 73), being longer than the edges ($n'$) in order to prevent jamming of the bit. The reamer ($k_1$) has reaming blades ($o$) (Figs. 71 and 74) pivoted in suitable recesses in its sides. The headed pins ($o_1$) bear against shoulders ($o_2$) on the bosses of the blades ($o$), and under action of coiled springs ($o_3$) abutting against the screw plugs ($o_4$), by which the bosses ($o_5$) containing the pins ($o_1$) are closed; these pins cause the blades to swing outward, and when the drill is withdrawn from the hole they fold against the reamer carrier ($k$) as soon as they meet the bottom edge of the tubing ($g$).

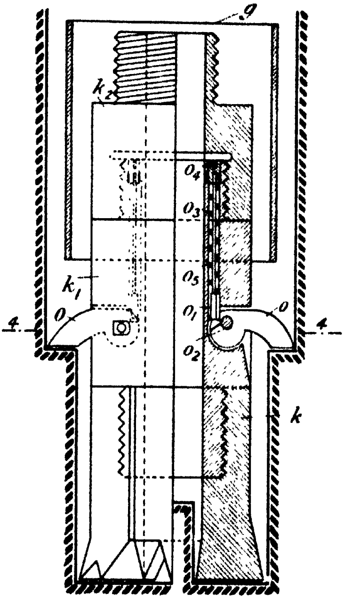


Fig. 72.—Fauck's Hollow Trepan

Fauck's improved "rig," patented towards the close of the year 1900, is shown in Figs. 75, 76. By means of this mechanism, the percussion drill secured to the rods is alternately raised and allowed to drop again, a number of blows of short stroke being executed in rapid succession. The "rig" is provided with a double driving gear, namely, a walking-beam and an eccentric shaft, upon which is loosely mounted a grooved pulley working in a bight of the suspension rope of the drill. As the rope runs to this pulley downward from a fixed point, and afterwards upward to a guide pulley arranged before the end of the walking-beam, the stroke of the drill is double the throw of the eccentric, but as the walking-beam swings, this double stroke is increased by nearly twice the stroke of the walking-beam. The weight of the rods is balanced by springs acting upon the walking-beam and the eccentric shaft. Originally an encased free-fall arrangement, of the Fabian type, was used, but has been almost entirely abandoned in favour of springs. This later development consists of an elastic suspension coupled with rapidity of stroke, so that the suspension rods, kept just in a state of tension, spring up after delivery of the

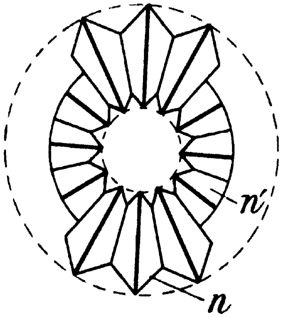


FIG. 73.

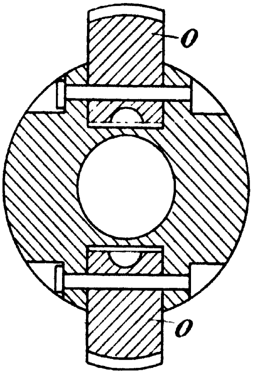


FIG. 74.

blow, and before they feel the effects of the shock. The number of strokes varies according to the depth of the hole, from 60 to 120 per minute. When at rest the trepan or chisel will just not touch the bottom of the hole, but when the rapidity of stroke reaches a certain point it beats the rockhead with every stroke, hence the necessity for the rapidity of reciprocation.

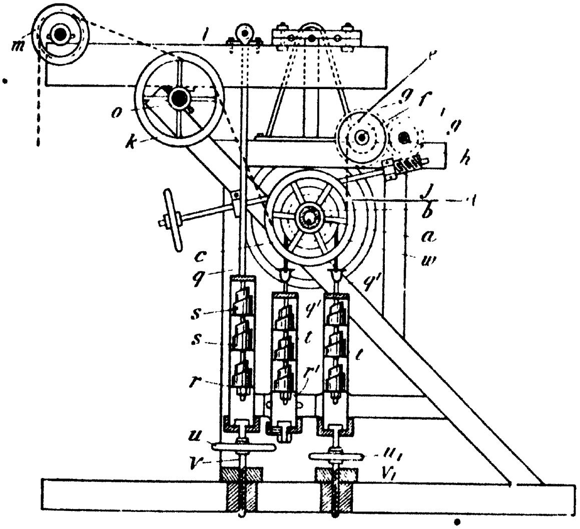


FIG. 75.—Fauck's Boring Apparatus.

In the sectional side elevation of the rig (Fig. 75), the eccentric shaft (*a*) has loosely mounted thereon a brushing (*b*), upon which is loosely mounted the grooved pulley (*c*). The rope (*d*), by preference a flat one, comes from the reel (*e*), whose shaft (*f*) carries the toothed-wheel (*g*) gearing with the toothed-wheel (*g'*) mounted on the shaft (*h*), which has also secured to it a worm-wheel (*i*) gearing with the worm (*j*), by means of which the rope can be paid out or drawn in according to requirement; (*l*) is the walking-beam, (*m*) the second guide pulley. The stroke can be altered at will, there being three different bearings provided. (*k*) is a guide pulley mounted on the shaft (*o*) of the walking-beam, (*ss*) are volute springs enclosed in tubes (*tt*) which, by means of the hand-wheels (*u*, *u'*), can be put in tension. It will be seen that when the walking-beam is working, the pulley (*m*) in moving upward also acts upon the parts of the rope in front and rear of it, and thereby again increases the lift of the drill by nearly twice the stroke of the walking-beam.

Now,. by other boring operations, having for their object the securing of a core, it is necessary from time to time to withdraw the rods to obtain the same, occasioning thereby much waste of time and labour. According, however, to Herr Albert Fauck's invention of 1898, this is avoided. He noticed that when core-boring with percussion drills, the core gradually assumed a conical shape, in consequence of the wear of the inner surface of the tubular bit, and that if the worn bit was replaced by a fresh one, having the normal inner diameter, the bit got jammed upon the core, and afterwards the core was torn off by it, and this method of extraction he now carries out in regular practice.

In Fig. 76 it will be observed that the rope D is connected by means of the stirrup $B_1$ to the tubular drill-rod I, which enters the tubing J through the stuffing-box $J_1$, made integral with the cap $J_2$, which is screwed upon the top section of the tubing in order to tightly close it. This cap is provided with a nozzle $J_3$ to be coupled with the hose L, through which a stream of water is forced down the tubing or casing of the hole, and ascending through the tubular bit and rods, carries along with it the sections of the core, which are prevented from clogging by the continuous shaking of bit and rods. The vessel M receives the portions of the core so carried up, and the hose L carries off the water. When not forcing up a core the water passes down the rods in the usual way, the bottom of the hole being constantly flushed. The type of water swivel used with this apparatus is shown in Fig. 77.

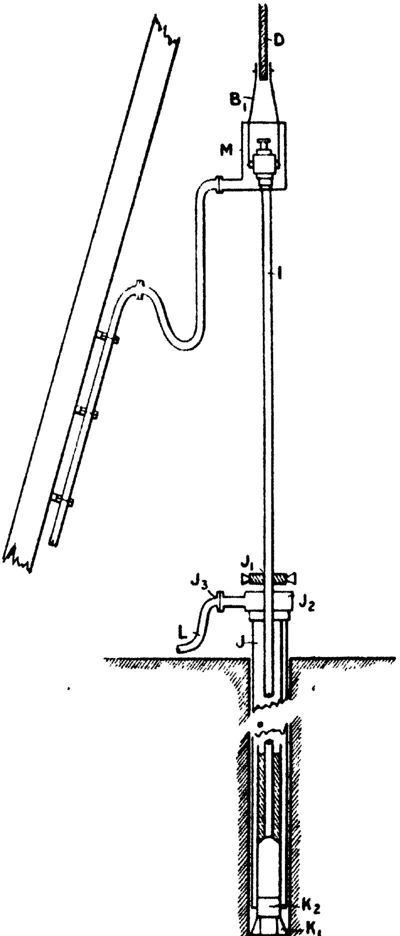


FIG. 76.—Fauck's Boring Apparatus.

Herr Fauck's system of boring, known as the "Rapid," is the property of Trauzl and Co. of Vienna, and has been extensively used in Galicia, Austria-Hungary, Russia, &c., both in boring for coal and petroleum, at depths up to 2638 feet, and, which is remarkable, up to 1048 feet with hand boring. The number of strokes, which can be made as short as $\frac{3}{4}$ inch, are capable of being increased to 250 per minute, and the average rate of advancement varies from 46 to 65 feet per twenty-four hours, and in unusual cases has attained $98\frac{1}{2}$ feet, though these rates would be much diminished if the descent of the tubing was made simultaneous with the boring, necessitating, as this would, the use of the enlarging tool.

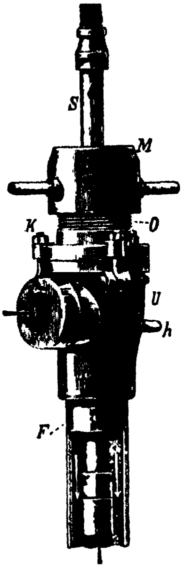


FIG. 77.—The Trauzl Water Swivel.

**The Reinpreussen Apparatus,** patented by Trauzl & Co. (1898), has achieved remarkable results. In this apparatus the reciprocating movement of the cable is realised by the oscillation of the drum and winch, on which it is directly rolled (Figs. 78 and 79). To effect this the rotating motion of the arm worked by a strap from the "locomobile" E is transformed into an alternating movement by a mechanism composed of the connecting rod *m* of the lever *l*, and the connecting rod K. In order to allow of the winding of the cord and permit of the progress of boring, the connecting rod indirectly works the drum. It commands the collar B lying against an endless screw A, which works into the helical gear *r* fixed on the drum, and moving in a cavity arranged in the collar. The rotation of the drum can therefore be produced independently of the collar, and the rods raised and lowered. An arrangement whereby the rods are counter-balanced and the impeller assisted is shown: the collar B is worked by the rods of a plunger-piston $K_1$

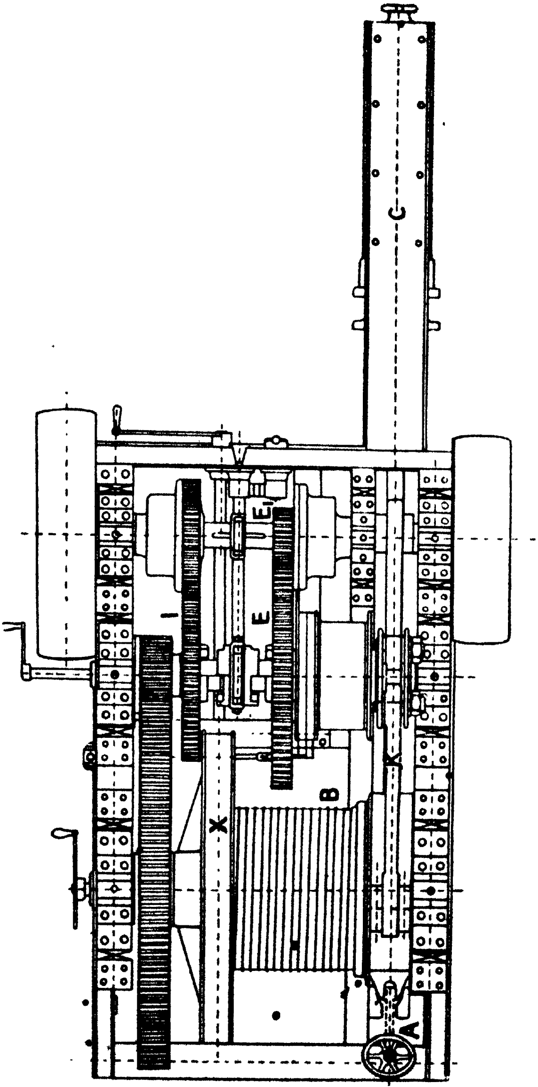


FIG. 78.—Plan of the Reinpreussen Boring Engine.

moving in the cylinder C, the pressure on the piston is regulated at will from the steam from the boiler. The collar consists of two pieces, and, opening it, the screw A is joined to the helical wheel *r*. The drum worked by the one or the other of the gearings acts then as a winch.

In the northern end of the Ruhr coalfields, in the neighbourhood of Recklinghausen, two holes were put down, one to a depth of 1640 and the other to 1968 feet.

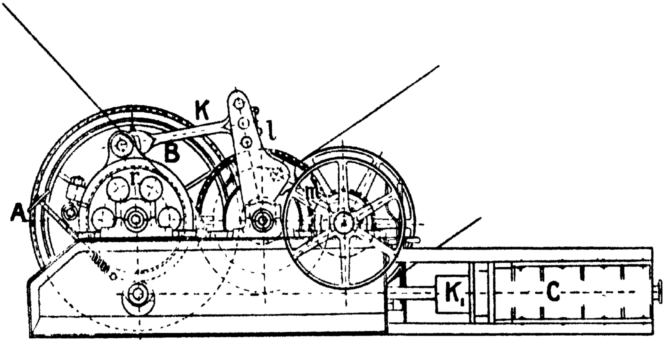


FIG. 79.—Side Elevation of the Reinpreussen Boring Engine.

In one of these the average rate of boring was 106 feet, and in the other 157 feet, per twenty-four hours.

**The Raky System of Boring.**—This system of boring has gained great repute from the remarkable results which it has furnished.[1] By it was sunk the deepest bore-hole in Belgium, viz. that at Gheel, No. 35, which attained a depth of 4071 feet.

Figures published at the time of the Dusseldorf Exhibition (in 1902) show the following:[2]—

---

[1] For an admirable account of this system of boring see the article in the *Revue Universelle des Mines*, July 1896, by M. Martin Buhrbauck, entitled *Note sur le procédé de sondage du Système Raky.*

[2] The measurements, which were given in metres, have been converted into feet.

TABLE XVIII.

| Country. | No. of Borings. | Average Daily Advancement in Feet. | Average Rate of Boring in Feet. | Maximum Attained in Feet. | Depths in Feet. |
|---|---|---|---|---|---|
| Westphalia . . | 12 | 33 to 116½ | 70¾ | 349¼ | 1414 to 3875 |
| Alsace-Lorraine. | 10 | 26½ ,, 60 | 41¾ | 154 | 722 ,, 3284 |
| Belgium . . . | 8 | 54½ ,, 120½ | 82 | 360¾ | 1516 ,, 2831½ |

The value of these figures,[1] however, is somewhat depreciated by the fact that both percussive and rotary boring were employed, the latter always the slowest, and no distinction was made when noting the rates of progression.

Fig. 80 represents the surface part of the apparatus, which is all that calls for description. B is the walking-beam suspended by a frame at the cross-piece O, which is itself supported by the two rods TT inversely screwed at their upper ends, and resting by the nuts E on the movable cross-beam or breast-summer M, between which and a second cross-beam N which rests on the framework are a series of strong steel spiral springs (30 to 40) R, which render the bearing elastic. The boring rods *t*, made of 2-inch Mannesmann tubing in 5 m. (16 feet 5 inches) lengths, are held by the keys K and K′, which rest on the walking-beam by a joined plate *p*, and their weight is counterbalanced to some extent by the weight *b*. The point of application of the connecting rod is near *b*, the oscillation given by it being amplified by the springs. For the system to be effective, however, there should be a rather considerable weight of rods at work.

The gradual lowering of the rods as the work of boring proceeds, is made by the aid of the keys (which are shown in Figs. 81 and 82). The gland in which the clamp turns is provided with cheeks and screws for fixing the rods in any position, and a handle to the clamp enables the foreman to turn the bits round. The lowering of the rods, without stopping the boring, is carried out in the following manner. Each key is composed of two similar parts held by a joint on the one hand, and by a closing device on the other. Each of these parts is composed of a support, and a jaw *m* moving in that support,

---

[1] According to M. Habets, *Professeur à la Faculté Technique* in the University of Liége, 18 to 20 m. of boring per twenty-four hours is usual in borings of 400 m. depth, through shaft strata, but this is reduced to 7 m. in coal measure rocks, and the average does not exceed 2·50 m. in hard sandstone.

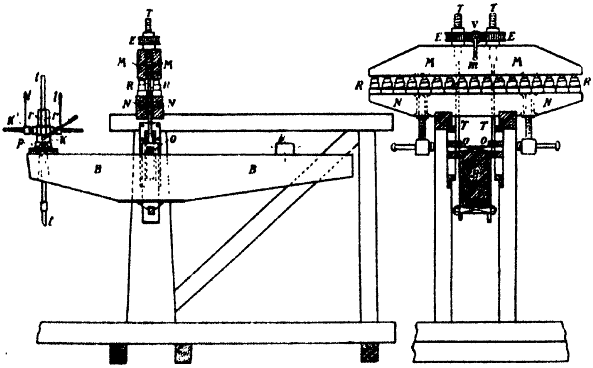


FIG. 80.—Raky Boring Apparatus.

the movement of the jaw being governed by the lever *t*, through the medium of a screwed rod, as shown. Now the threads of the screw of the jaws are contrary, so that, if the clamp be locked, a rotating movement in the same direction given to both levers has the effect of withdrawing or approaching the two jambs. The clamp being locked on the bore-rod, a short quick movement suffices to loosen it. The clamps are at right angles, the upper one differing from the lower one in that it carries in four cylindrical cavities in the support four small rods *r*, with pistons working against springs (see Fig. 82, which represents a section in which the upper clamp is omitted for the sake of clearness). The studs or pins project for a distance of 1 to 2 c.m., and when the bit is

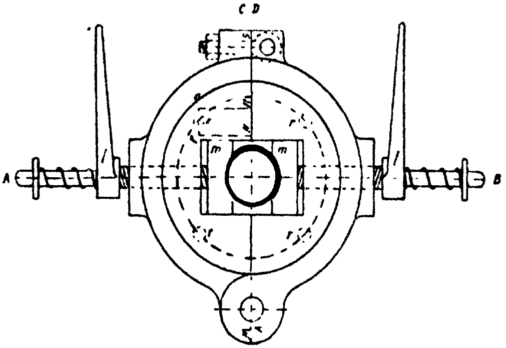


FIG. 81.—Clamp used in lowering Rods with Raky Drill.

to be lowered a little, all that is necessary is, the lower clamp being locked, to lock the upper clamp which is held up by the studs, then releasing the lower clamp the

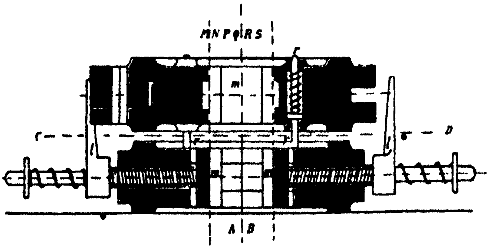


FIG. 82.—Clamp used in lowering Rods with Raky Drill (Section).

weight of the boring rods bears on the springs and compresses them, bringing the two clamps into closer contact; the lower clamp is then locked, and the upper one released, and at once rises owing to the expansion of the springs by from 1 to 2 c.m. The handles serve also as brace-heads for turning the rods. They can, however, only be employed for the smooth part of the rods. For the passage of the screw joints the following contrivance is resorted to. The top of a rod having reached the clamps, the rods T (Fig. 80) which support the cross-piece O are simultaneously lengthened by the rotation of the handle *m*, the endless screw V governing the rotation in a contrary direction of the nuts E, so producing the lengthening of the rods T. After sufficient advancement this is stopped, the rods are suspended by the winch cable, the clamp relieved refixed above the screw joint, the walking-beam raised, and the boring proceeded with.

When it is necessary to raise the column of rods, the walking-beam is slid back into the frame.

It must be remembered that actual boring does not commence until the springs against which the walking-beam acts have been put into a state of oscillation. The contact of chisel with the rock-head is of extremely short duration, which allows of a great number of strokes per minute—80 as against 30 with rigid rods with free-fall, and 60 in the Canadian method.

In the year 1896,[1] in a boring for petroleum at Gunstell, in Alsace, twenty-six working days were occupied in erecting the plant, and 332 hours were absorbed in actual boring to a depth of 1304 feet 6 inches, and it took 91 hours to tube out the bore-hole. The speed, therefore, of the boring was nearly 4 feet per hour, and the cost, including wages, repairs, material, and transport, but no capital charges, was about 3s. 4d. per foot.

**The Vogt System of Boring,** patented in Germany in 1897, is very similar to the Raky, the chief point of difference being the somewhat altered arrangement of the walking-beam springs.

---

[1] *Glückauf*, 1896, vol. xxxii. pp. 225–232.

Other Continental systems are the *Verbunt*, in which there are no springs, patented in Germany in 1902, and the *Hackenburg*, which differs largely from those already described, but, as it does not allow of counterbalancing the rods, is not under ordinary conditions effective below 300 to 350 m., though remarkable results have been obtained in penetrating Tertiary rocks, holes having been advanced by more than 328 feet (100 m.) in twenty-four hours. The apparatus is, however, complicated and difficult to supervise.

**Boring by Hydraulic Shock.**—Although in the majority of cases, where boring is performed through the medium of rods, the great weight of the rods is counterbalanced to greater or less extent, yet the putting into motion of the mass necessitates a considerable expenditure of energy, which is largely lost, being chiefly absorbed by the friction due to the rods rubbing against the sides of the hole, which has the effect also of weakening the lateral support of the hole. Furthermore, the importance of the masses in motion limits the rapidity of the stroke, whereon depends the useful effect of the boring apparatus, and the vibration of the rods tends in the long run to produce their rupture. In hydraulic-ram boring, however, the hollow rods or tubes being stationary, except for the turning movement and occasional lengthening of the rods, they suffer little or no shock.

**The Wolski and the Frieh Boring Apparatus.**—This apparatus, the property of the German Deep Boring Company of Nordhausen (*Deutsche Tiefbohr-Aktiengesellschaft*), and shown by them at the Liège Exhibition of 1905, is worked on the hydraulic-ram principle, a number of borings having been executed by it with very satisfactory results.

The principal parts of the apparatus are illustrated in Figs. 84 and 85.

Herr Wolski[1] explains the action of his boring-ram by Fig. 83. A stream of water being sent by the pump through the tubes will at first rush out freely through the open valve W. But when the stream has attained a certain velocity it will exercise such a pressure on the valve plate from above that the resistance offered by the spring will be overcome and the plate be thrown with force against its seat, the column of water in the tubes V will be suddenly stopped and the tool driven down by the shock compressing the spring Z. On the exhaustion of the kinetic energy of the water column by the work done a reaction follows, the buffer springs Z again expanding the column of water is thrown back in the tubes V, and the pressure of the pump (or the air contained in the air vessel) is for a moment neutralised, the valve plate opens, the bottom of the hole rinsed out, and the action of sudden compression again repeated.

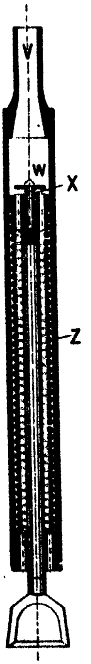


FIG. 83.—Diagram Explanatory of the Action of Hydraulic Boring.

One valve plate, one piston, and two springs constitute the only movable parts, and for narrower dimensions of hole a single elastic steel-lamina (similar to the tongue of a reed pipe) may be substituted for the valve plate and valve spring.

The effective pressure working the piston of the cutting tool is not the pressure caused by the pump, but the five or ten times greater pressure of the water shock; its surface can be made five or ten times smaller, which goes far to solve the difficulty of the narrow width necessary in deep borings.

---

[1] "The Hydraulic Ram-Boring Apparatus," by W. Wolski.

A piston 3·1 square inches (20 sq. cm.), 1·9685 inch (50 mm.) diameter, gives an effective pressure of as much as 4409·2 to 8818·4 lbs. (2000 to 4000 kgs.).

In a boring apparatus using moving rods the mass striking the bottom of the bore-hole with small velocity is 1100 to 3300 lbs., whereas with the hydraulically transmitted force the weight of the moving mass is only from about 66 to 154 lbs., but the rapidity of stroke is very great.

The two factors[1] that govern the force of the chisel blows are the valve adjustment—as the velocity of the water at the moment of shutting the valve is identical with the stroke velocity of the column and so determines the pressure of the piston—and the length of the striking column, which defines the duration of the pressure acting on the piston. The latter is determined by the distance between the striking-tool and the air-vessel, for the air-vessel constitutes an elastic part yielding to pressure, and so forms an interruption in the column of water of homogeneous elasticity, causing a reflection of the waves of compression.

Fig. 84 represents the arrangement of the deep-boring ram. The valve seat is a steel cylinder with a central hole and a row of parallel holes around it, all of which are simultaneously shut (or opened) by a thin elastic steel-plate ring. The valve spring works in a cylindrical widened groove of the valve seat; its effect can be strengthened or weakened by putting under it thin steel-plate rings of various thicknesses. A short central tube acts as guide for the valve plate, and two displaceable check notes on it form its upper stop.

The valve being open the water flows through the row of holes, through the mantle tube and the bore-shoe to the chisel, and clearing the bottom of the hole, rises to the surface again. When the valve is closed the pressure of the water shock is spread through the valve-guiding tube into the working cylinder, a tube of chilled steel, in which the piston plays.

---

[1] Herr W. Wolski, in his paper on the "Hydraulic Ram-Boring Apparatus," considers the subject very clearly fro [illegible] mathematical and physical standpoint

The bit is an eccentric step chisel attached to the piston-rod by a ball and socket joint to obviate shaking, the cylindrical part being guided by four ledges in the interior of the cast-steel bore-shoe, its flat part playing in a slit of the bore-shoe.

The back-lifting springs rest on the bore-shoe and press with their upper part, by means of a short bit of tube, against the piston. If, therefore, it is desired to draw out, examine, or change any of the parts connected with the chisel or the piston or its leather packing, all that is necessary is to unscrew the bore-shoe. The screw joints throughout are conical, and the stroke-tube, with its thick walls, is also composed of parts with conical screw joints, and has a total length of 10 to 20 metres (32·81 to 75·62 feet).

Fig. 85 shows the most approved form of air-vessel. The wall of the tube is perforated by a great number of very small holes A, which are covered by an indiarubber hose B fastened at both ends, the whole being contained in a steel tube C hermetically closed at both ends. Air is pressed into the space between the steel mouth and the hose by means of a small valve D to a certain pressure. During boring the hydraulic pressure (hydraulic *plus* pump pressure) and the pressure of the inclosed air act and re-act against each other, the indiarubber now expanding and now contracting, constitutes the elastic separation between the air and the water space.

If cores are desired they can be obtained by using striking crown in place of a chisel, and some other

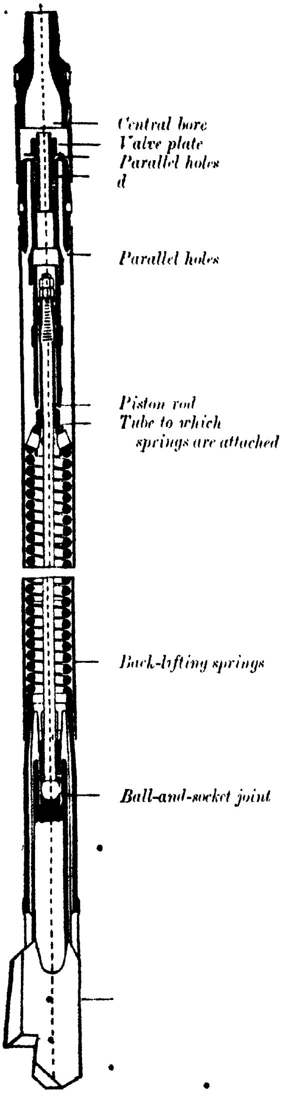


FIG. 84.—The Frieh Hydraulic Boring Apparatus.

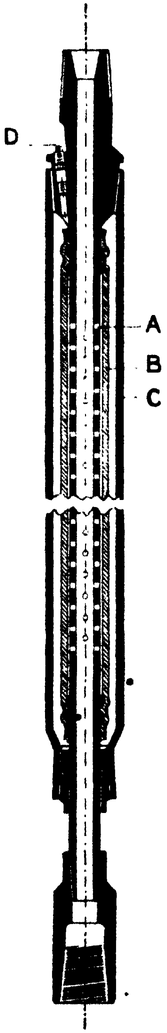


FIG. 85.—Air-vessel of the Frieh Hydraulic Boring Apparatus.

slight modifications, such as a fixed central core tube of considerable length.

The rapidity of blow attains to 12 strokes per second with the Howarth and Wolski motors, and from 80 to 100 strokes Pruszkowski's motor.[1]

In some trials made on blocks of hard sandstone the Wolski apparatus bored ·65 metres (2 feet 1½ inches) per hour under a pressure of 12 atmospheres, and with a water consumption of 5 litres (about 13¼ gallons) per second, the diameter being 8 inches. In soft sandstone the rate was 7 metres (22 feet 1½ inches), which are very remarkable results.

## ROTARY BORING

Rotary boring apparati are composed of three principal parts:—

1. The driving gear.
2. The rods.
3. The drilling apparatus.

The rotation of a crown attached to the bottom of the hollow rods acting by attrition wears away or cuts an annular hole in the rocks, and so forms a central core over which the hollow boring-rods pass, and which is ultimately broken off, being retained in the core barrel intervening between the cutting crown and the rods, and is brought to the surface when the rods are raised.

The great advantages that rotary boring processes possess over the percussive methods are, that the crown being continually applied in cutting, the driving force is more economically utilised than in boring by percussion, and (undoubtedly the chief advantage) that when penetrating compact strata the rotary systems provide, as cores, very complete sections of the rocks penetrated, these cores being far superior both in respect to the proportion of rock obtained and as to continuity of operation, to those which the annular trepan gives in the percussive methods. In the earlier stages of the rotary systems considerable loss of cores was occasioned, owing to the inefficient retaining apparatus, but this has been so perfected as to practically obviate such loss when boring in fairly firm strata; but when passing through shaley rocks or marls, which easily disintegrate, it is seldom that any but a small proportion of the actual section is retained as core, so that although when boring through hard and highly siliceous rocks the internal diameter of the crown may be very small, when penetrating rocks of a softer nature the larger the diameter the higher will be the percentage of core obtained. In fact, it has been estimated that this cohesiveness of the rock is proportional to the square of the diameter of the core. For this reason it is seldom advisable to make a hole of less than 3 inches diameter when boring in coal measures. The three commonest ways of boring by rotation are with—

---

[1] *Revue Universelle des Mines*, January 1904, p. 73.

(1) The diamond borer.

(2) The serrated steel crown borer (Davis calyx system).

(3) With chilled steel shot.

The use of the diamond was first successfully used for drilling purposes by M. Leschot, a French engineer, for making blasting-holes in the St. Gothard Tunnel, and the type of crown which he then made use of has been little altered since.

**The Diamond Drill.**—The great advantage this drill possesses over others is that it drills a smooth hole in a vertical or inclined direction, and provides, at the same time, a more or less complete section, as a core, of the strata penetrated. The drill consists of a column of hollow iron or steel rods screwed together, in the American and English patterns, usually in 5 or 10 feet lengths, and in continental practice usually in lengths of 5 metres, rotated by an engine through a shaft and gearing, and fed forward either by gravity, screw, or hydraulic action. At the lower end of the rods is placed the bit or "crown" (Fig. 86) studded with black diamonds (borz, bort, carbonatos, or carbons). A current of water forced down through the hollow rods washes away the sediment and keeps the diamonds cool, which, as the crown is usually rotated at a rate of from 90 to 125 revolutions per minute,[1] is very necessary. At intervals, usually after drilling 10 feet, the rods are withdrawn by means of the hoisting winch, and the core extracted from the core barrel.

Fig. 87 illustrates the form of drill commonly adopted. On the Continent, especially in Germany, the diameter of the crown varying between 12 to 17 inches, whilst in the American and British patterns the former figure often constitutes a maximum. The number of diamonds is usually six in crowns of 2 inches diameter, and eight in sizes of 3, 4, and 5 inches, whereas from ten to twelve are used in 7-inch crowns.

The circulation of the water through the crown is facilitated by three to eight grooves channelled in the interior as well as the exterior surface. The crown, which is always only a few inches in height, is screwed into the core barrel, of which the exterior diameter is slightly less than that of the crown, in order to facilitate the passage of the water current and the mud, and its length is generally from 20 to 30 feet, though it is seldom that it is possible to continuously bore this depth. It is

---

[1] And sometimes even as high as 250 revolutions per minute.

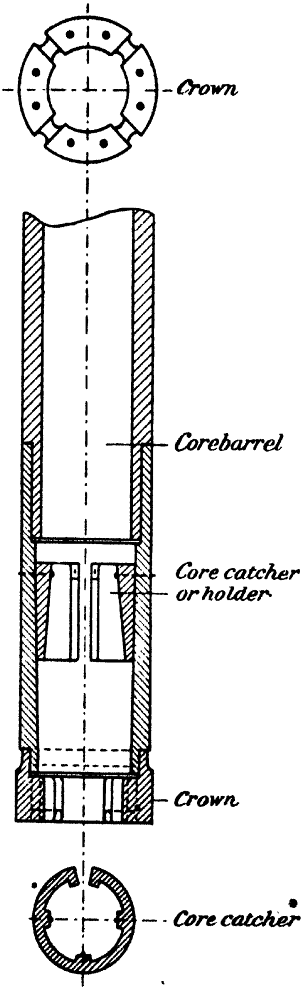


FIG. 86.—Crown and Core Barrel of Diamond Drill.

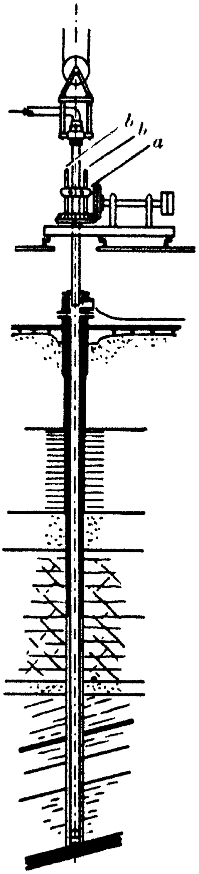


FIG. 87.—Diamond Drilling Apparatus.

given this length in order that it may serve as a guide to the borer and assure the rectitude of the hole.

Between the core barrel and the crown is placed the arrangement for holding the core; it usually consists of a split or expanding ring working on a conical seat, as in Fig. 87, and 4, 5 and 6, Fig. 88. So long as the cutting tool is pressed against the bottom of the hole and the core is passing up the core barrel, the position of the split ring is in the larger diameter of the seat, but when the rods are raised the ring is pressed down and, contracting, holds the core fast (Fig. 86). The rods which are attached to the core barrel through the medium of a reducing piece are of a diameter usually less than in

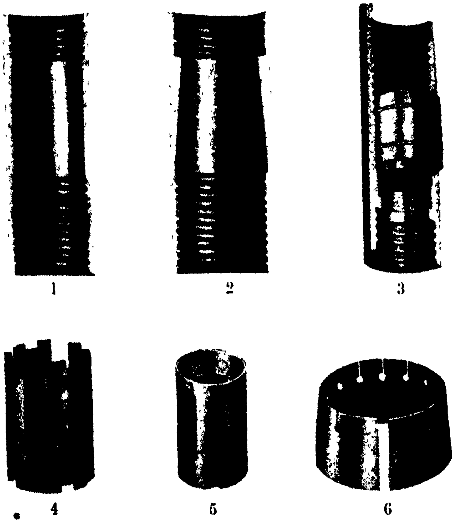


Fig. 88.—Types of Sullivan Core-lifters or Holders.
1. Bevel core-shell; 2. Straight core-shell; 3. Special shell and wire-spring core lifter; 4. "Cossette" core-lifter; 5. Sheet steel core-shell; 6. Standard "split ring."

those cases where hollow rods are used in percussive boring, as they are not subjected to the same shock or vibratory action. They terminate in a swivel, which also sometimes serves as the junction with the suspension cable (see Fig. 87, and (4), Fig. 89).

**British and American Types of Drill.**—Figs. 90 and 91 represent the surface plant of the American (Sullivan) type of drill, that shown in Fig. 91 being capable of drilling to a depth of 3000 feet, and giving a core $1\frac{3}{8}$ inches diameter, is very largely used all over the world. This drill has bored a hole 2350 feet deep without it being found necessary to counterbalance the rods.

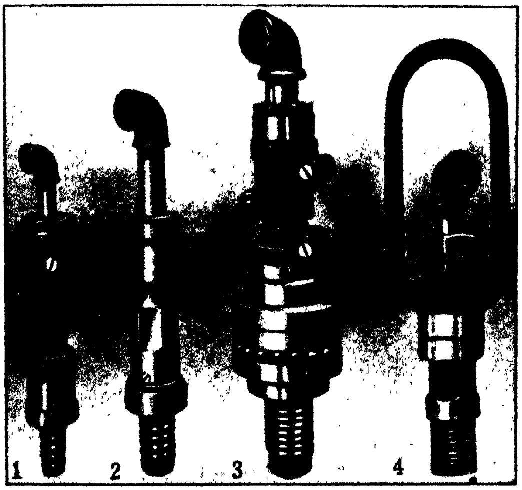


Fig. 89.

1. Common water swivel with steam lubricators; 2. Common water swivel; 3. Improved ball-bearing water swivel; 4. Special combined water swivel and hoisting plug.

In the type shown in Fig. 91, the advance or feed of the rods is secured through the medium of a single cylinder

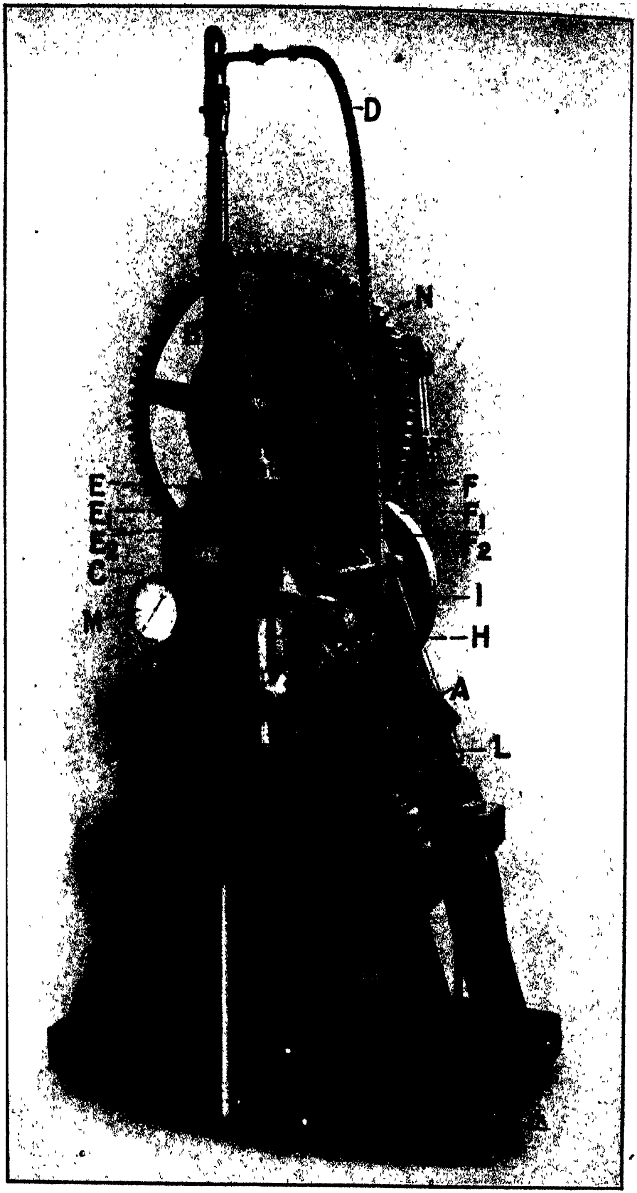


FIG. 90.—Sullivan Diamond Core-drill with Screw Friction Feed. Capacity, 1500 feet; diameter of core, 1⅛ inches.

A, Steam cylinder; B, Feed screw; C, Bevel wheel; D, Hose; E, $E_1$, $E_2$ and F, $F_1$, $F_2$, Differential feed gear; G, Drill spindle; H, Countershaft; I, Clutch; J, Toothed wheel; K, Screw nut; L, Toothed wheel working J; M, Thrust indicator.

hydraulic piston, the action of which is made clear by the

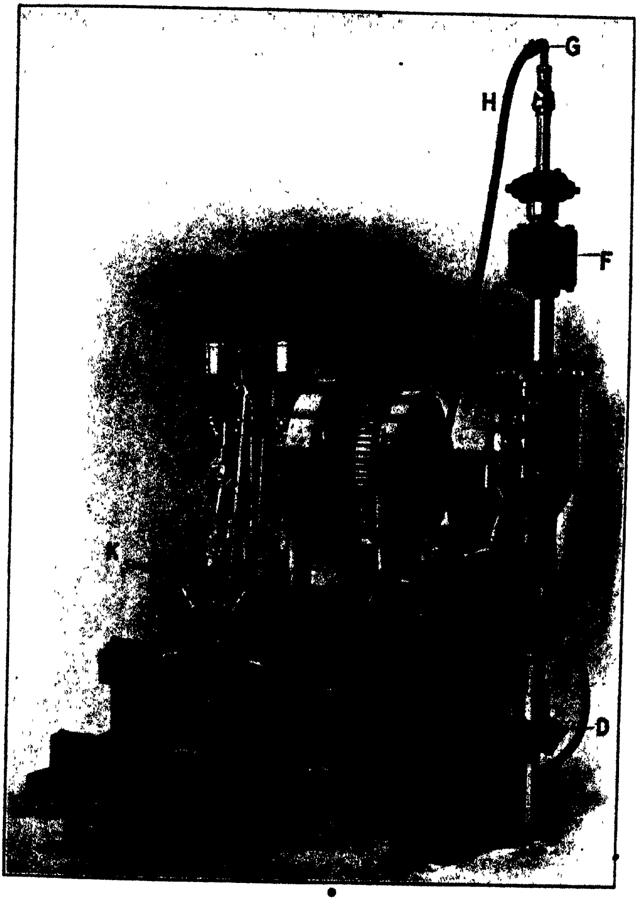


FIG. 91.—Sullivan Diamond Core-drill with Hydraulic Feed. Capacity, 3000 feet; diameter of core, 1⅝ inches.

AA, Steam cylinders; B, Hydraulic feed; C, Drill rod; D, Chuck; E, Bevel wheel attached to drive rod; F, Thrust box; G, Water swivel; H, Hose; I, Drum of hoist; JJ, Brake straps; K, Lever working brake straps.

sectional sketch, Fig. 92. In this, A is a hydraulic cylinder.

in which moves the piston B, attached to the piston rod C. E represents a tee by which connection is made with the pump on the right-hand side, E on the left-hand side being the water-escape, the water being let in and out through ports and the brass tubes F. 1 and 2 are inlet valves, 3 and 4 being outlet valves. When 1 and 3 are open, 2 and 4 being closed, water is pumped in above the piston and escapes from below it, so the piston will move downward; when 2 and 4 are open and 1 and 3 closed, the reverse is the case. By closing 3 the feed is instantly stopped. G is the thrust-plate to which the upper end of the piston rod is screwed, H being another thrust-plate connected to the former by means of studs. Between these plates are, on each side of the collar, two sets of friction-ball roller bearings I of the drive rod J. It is through this collar

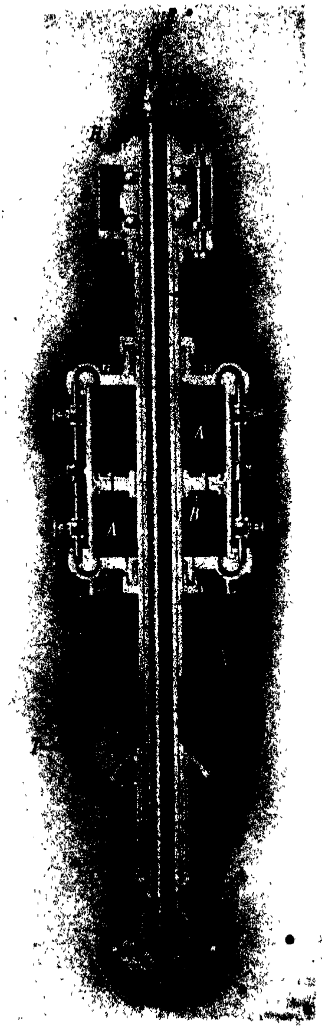


Fig. 92.—Sectional View of Single Cylinder Hydraulic Feed Mechanism.

that the vertical motion of the hydraulic piston is transmitted to the drilling bit. The rod J is driven by the mitre gear K. The boring-rods pass up through the drive rod to which they are clamped by the chuck L screwed into the bottom of the drive rod. The rotating drive rod moves freely through the mitre gear, the feathers of the latter sliding in grooves in the former. By means of the hydraulic apparatus the feed may be increased, diminished, or reversed, while the drill is running. All shock, such as would occur, for instance, were a cavity struck, is prevented. Pressure gauges on the supply and discharge pipes indicate the variations in the pressure on the bit.

The hydraulic feed is best adapted when the boring is through soft as compared with hard sandstone, so the screw or *friction feed* has been designed to meet cases where a positive uniform rate of advance, regardless of the hardness of the rock, is desired. It consists of a system of differential gearing, which is friction driven. The motion from the spindle of the drill (G, Fig. 90) is communicated in the following manner. $EE_1E_2$ are connected with the bevel wheel C, so that when it rotates they move in like manner. The geared wheels $FF_1F_2$ are loose upon the countershaft H, but any one of these can be fixed fast by putting the clutch I into action. J is a toothed wheel fixed to the bottom of a feed nut K through which the feed screw B works, so that when J is rotated it causes C to move upwards or downwards according to the direction of rotation, and L is a similar wheel to J, into which it works.

In feeding, that is to say, when one of the toothed wheels $FF_1$ or $F_2$ is clutched—say, F—E rotates F which turns L, which works J, and so operates the screw feed. If $EE_1E_2$ have a few more teeth than $FF_1F_2$, a single

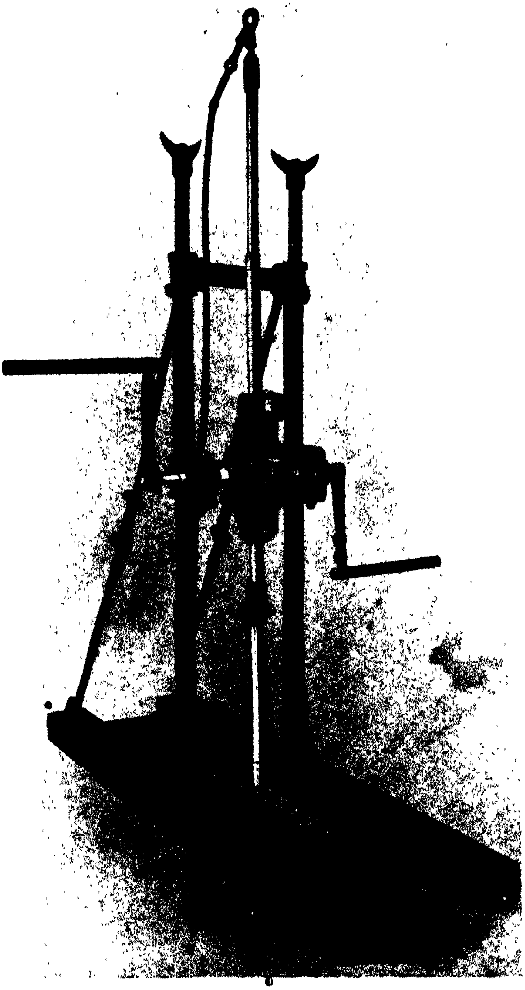


FIG. 93.—Sullivan Hand-power Diamond Drill with Screw Friction Feed. Capacity, 350 feet; diameter of core, $\frac{15}{16}$ths inch.

revolution of E will cause F to make more than one rotation, so that J will also rotate faster than B, and B will slowly descend. By means of this system a positive and uniform rate of advance, ranging in different machines from $\frac{1}{50}$ to $\frac{1}{2400}$ of an inch to each revolution of the bit can be given. In the illustration it will be observed that three different rates of advance are possible. M is a thrust indicator, a gauge which is graduated up to 5000 lbs., and shows the amount of pressure exerted on the bit, so enabling the boring superintendent to determine when the drill passes from stratum to stratum of varying degrees of hardness. N represents the drum of the hoisting apparatus, round which passes a steel wire rope for raising the full weight of the rods. This drum, which is controlled by means of a powerful wood-lined brake, operated by a hand lever and screw or cam, and adjustable for wear, is capable of being easily put in and out of gear.

Figs. 87, 90, 91 show steam-driven drills, and Fig. 93 a hand-worked drill, the latter for boring to shallow depths. Electricity, compressed air, or gas-engines are also sometimes used for driving diamond drills.

The capital cost of the drills would be about as follows:—

*Sullivan Improved, Class "B,"* Fig. 91, capable of boring a $2\frac{1}{16}$ inch diameter hole to a depth of 3000 feet, and giving a core $1\frac{3}{8}$ inch diameter. Requiring 15 horse-power to drive the drill, with hydraulic feed, would cost in America, with partial equipment, about £583.

*The Hand-power "Bravo" Type*, Fig. 93, capable of drilling to a depth of 350 feet a $1\frac{3}{16}$ inch hole, and giving a core $\frac{15}{16}$ inch diameter with screw feed, costs in America about £83.

The Sullivan Company have designed the ingenious device illustrated in Fig. 94 for protecting the core, when

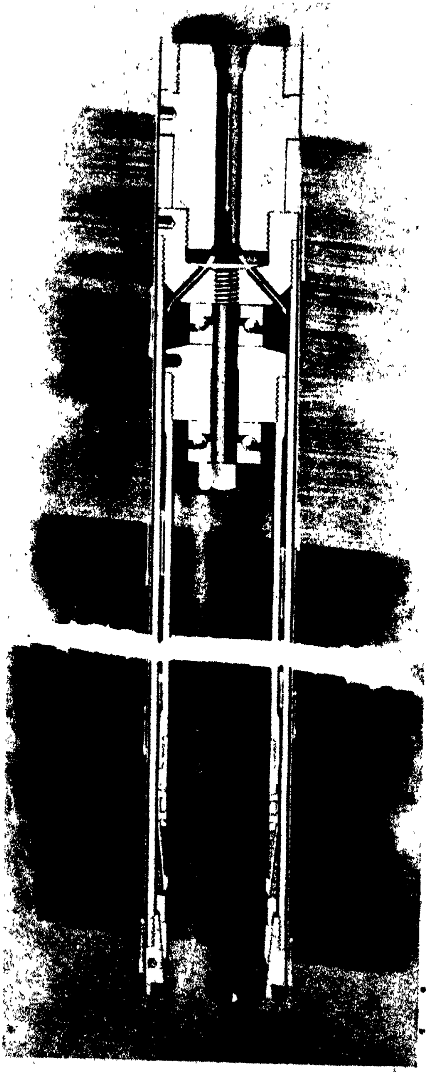


FIG. 94.—Sullivan Double Tube Core Barrel passing through a Coal seam. The arrows indicate the course of the water.

passing through such soft material as coal, from the denuding action of the water current, and the constant rubbing of the rotating core-barrel. It consists of a double casing; the outer one being attached to the drill rods, rotates with them, carrying with it the diamond crown and the core lifter, whilst the inner casing being suspended on ball-bearings remains stationary; the core therefore is protected from constant rubbing, and the water is conveyed to the bottom of the hole through the channel between the two casings.

Fig. 95 explains the several stages of "setting" a diamond bit: 1 is the blank bit, the positions to be occupied by the carbons being shown marked off on 2; in this case there are eight equal divisions, *a*. Having marked off the positions, suppose it is intended to set an outer diamond, a hole *z* is bored in from the side of the bit with a breast-bit, and a seat for the diamond carefully cut out with a small chisel as in 3; the cavity being correctly formed, the carbon is placed snugly in it (4), and by means of caulking-chisels and dull-pointed punches the metal is drawn up round it by making a cut about $\frac{1}{8}$ inch distant, on either side of the stone, and then caulking with the dull-pointed punch. Care must be taken not to hit the diamond, for though it will withstand very considerable pressure, a slight blow will shatter it. Copper is sometimes used for caulking up the stone. The amount of clearance necessary varies with the character of the rock; for boring through hard siliceous strata a clearance of $\frac{1}{64}$ inch on each stone will suffice, but $\frac{1}{32}$ or more is necessary in the case of soft rocks. The stones being set, the water grooves, shown in 6, are cut across the face and down the inner and outer sides of the bit.

Remarkable results have been obtained by diamond drills; the Class "P" Sullivan Drill, the rated capacity of

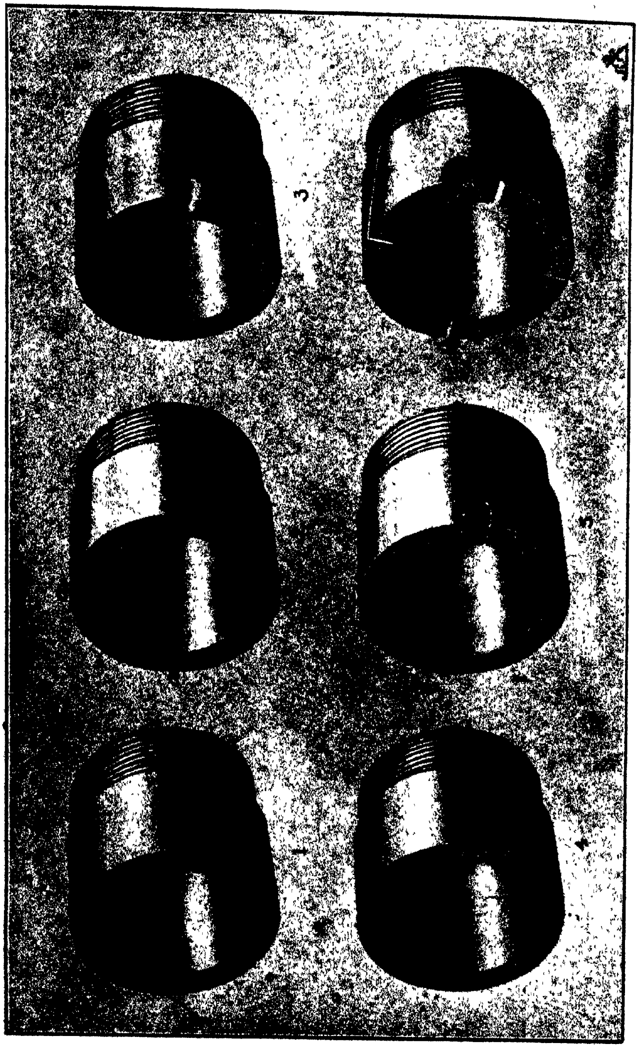


FIG. 95.—A Diamond Bit in the several Stages of being "Set."

which is 4000 feet, has bored holes in South Africa to a depth of 5560, 5582, and 6340 feet. In the case of the 5560 feet hole which was put down at Doorkloof (Transvaal), fourteen months were absorbed in drilling, a working day being twenty-four hours. For the first 700 feet a 2-inch core was extracted, the total weight of the rods being between 15 and 16 tons, and they were hoisted in 50 feet lengths, a 66 feet tubular steel derrick being used for the purpose. Towards the final depth from seven to ten hours were consumed in raising and lowering the rods.

The particulars of the cost of the principal parts of this drill are as follows:—

| | | |
|---|---|---|
| 1. | "P" drill and equipment | $4300.00 |
| 2. | 25 horse-power boiler mounted on wheels, with injector and complete fittings | 585.00 |
| 3. | 1 special duplex steam pump, size 7 × 4½ × 10 | 225.00 |
| 4. | 16⅔ feet, 2-inch suction hose, with connections and strainer, with union | 15.00 |
| 5. | 2800 feet extra drill rods, size "N" (10-feet sections), making 3000 feet with those in equipment, at $100.00 | 2800.00 |
| 6. | 24 extra blank bits, size "N," at $1.75 | 42.00 |
| 7. | 6 extra core lifters, size "N," at $3.15 | 18.90 |
| 8. | 4 extra core shells, size "N," at $5.00 | 20.00 |
| 9. | 1 cross chopping bit, size "N" | 10.00 |
| 10. | 100-feet drive pipe (or stand pipe), size 4½ inches, at $1.25 | 125.00 |
| 11. | 1 steel drive head, size 4½ inches | 11.00 |
| 12. | 1 steel drive shoe, size 4½ inches | 11.00 |
| 13. | 1 drive pipe chopping bit, size 4½ inches | 7.50 |
| 14. | 1 pair drive pipe clamps, size 4½ inches | 8.00 |
| 15. | 1 cast iron drive block, weight 550 lbs. | 21.00 |
| 16. | 200-feet casing pipe, size 3 inches, style flush coupling, 10-feet lengths, at 95 cents | 190.00 |
| 17. | 20 pair protectors for 3-inch casing, at 60 cents | 12.00 |
| 18. | 1 pair casing pipe clamps, size 2 inches | 6.00 |
| 19. | 1 bushing "N" rods to 3-inch casing | 4.00 |
| 20. | 1 improved long reamer, size 3 inches | 38.00 |
| 21. | 1 extra reamer face, size 3 inches | 6.00 |
| 22. | 1 pipe cutter, cutting pipe to 2 inches diameter | 2.25 |
| 23. | 1 set pipe stocks and dies, threading pipe ½-inch to 2-inch diameter | 14.00 |
| 24. | 2 No. 14 chain tongs | 17.50 |
| 25. | 2 jack screws | 14.00 |

| | |
|---|---|
| 26. 1 each 7-inch single and double blocks, with 100 feet of 1-inch Manila rope . . . . . . . . . . . | 3.00 |
| 27. 15 feet of $\frac{3}{8}$-inch chain, with hook and ring . . . . . | 4.00 |
| 28. 1 flue cleaner, poker and ash hoe ; supplied only with boiler . | 6.25 |
| 29. 1 shovel, 2 crow bars, hand saw, files, and cold chisels . . | 6.00 |
| 30. 1 sledge, pick, auger, and axe, with handles . . . . | 3.50 |
| 31. 1 lot of small pipe, valves and fittings ; extra packing and waste . . . . . . . . . . . . . | 25.00 |
| Total price, without carbon, F. O. B. Chicago . . | $8542.90[1] |
| 32. 1 set carbon, 8 stones ; weight 20 carats, at———. (Price of carbon, which varies considerably.)[2] | |
| 33. Setting carbon in one of the above blank bits . . . . | $8.00 |
| Packing and boxing for ocean shipment, extra . . . | 100.00 |

Total weight of drill and outfit as above, about 44,800 pounds.

## Other Types of Diamond Boring Machines.—

Fig. 87 represents the arrangement which is generally adopted by German borers. The pair of mitre wheels as well as the axletree of the driving gear, and the mechanism of putting the apparatus in and out of gear, is carried by a carriage. When the rods have been lowered this carriage is put into place by the aid of screws and locked. The rods pass freely through the driving-wheel, the rotary motion being transmitted by a sliding block (*a*) of two pieces fastened to the

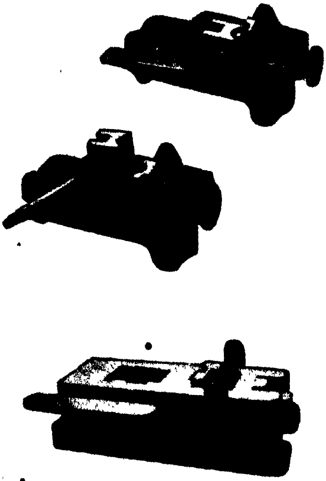


FIG. 96.—Safety-clamps for holding Boring Rods at the Surface of the Bore-hole.

---

[1] Say about £1780.

[2] Previous to 1880 the price per carat of *carbons* ranged from 8s. to 40s. In 1890 Kimberley *Bort* or *Borz* cost 60s. per carat, and it has been much higher than this. The present price (1906) of Brasilian carbons is about 375s. per carat.

rod by means of two strong bolts uniting the two pieces, the block being supported by two vertical guides (*bb*) carried by the wheel. In order to counterbalance the rods and relieve the crown of undue pressure, the gravity counterbalance is generally used, shown in rough sketch, Fig. 97. The suspension cable of the rods is wound on the drum of the winch *t*, which also works the counter-

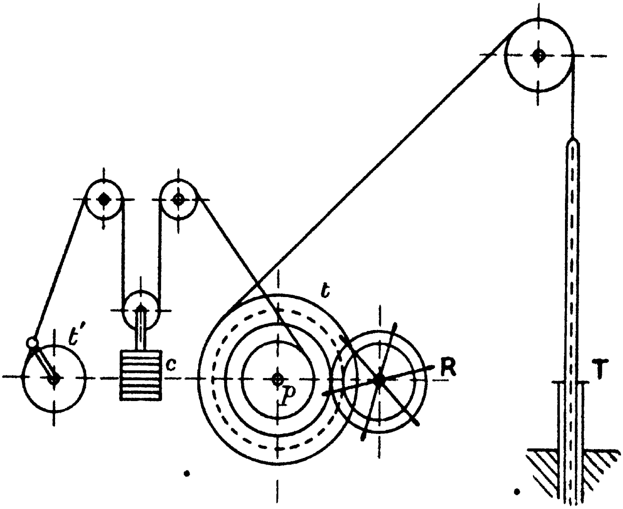


FIG. 97.—Counterweight Arrangement used when Boring with Diamond Drills in Germany.

weight *c*. The movement of the winch is controlled by hand through a governor R, connection with the drum being through the medium of toothed gearing or chain and sprocket. The reserve of cable on the winch *t* is sufficient to allow of the descent of one or several rods, and by turning *t'* there is restored to the counterweight the length of rope wound by the drum *p*. When the reserve of cable on *t* is exhausted, all that is necessary for its restoration is to unclutch the drum and so let it turn freely in the axle.

**Some General Considerations — Results and Costs.**—The cost of boring is greatly affected by the loss in diamonds. Besides getting broken, these are sometimes worked out of their setting. To recover lost stones a wad of wax or tenacious clay should be placed at the end of the rods, gently lowered, and forced to the extreme limit of the hole, and then gently withdrawn. Usually the more broken the strata the greater the loss in carbons; passing through conglomerates is a very fruitful source of loss.

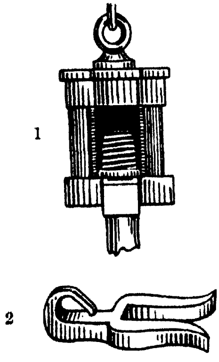


FIG. 98.

1. Arrangement fixed to head of rod to allow of its being drawn up or lowered.
2. Key for holding rod at the mouth of the hole (continental practice).

The consumption of coal may also prove an important factor in cost, and this of course is governed by the horse-power of the drill. A drill boring a 2-inch diameter hole (core 1⅜ inch) will require, when boring at about 600 feet depth, 2¾ horse-power. On pp. 82 and 151 the horse-powers required for boring deep holes have been mentioned.

The particulars of a bore-hole put down at Besuidenville (Rand), although not bored in search of coal, but in rocks much harder than coal measure strata, are of interest on account of the detailed nature of the particulars available. The depth of the hole was 3728 feet. The time occupied in its completion was 212 days. The rate of boring (through quartzite, conglomerate, &c.) was 17·58 feet *per diem*, external delays occupying twelve days. For the first 2000 feet a 2¾-inch diameter crown was used, and for the final 1728 feet a 2-inch diameter crown. Delays incidental to drilling, repairs, loss of carbons, &c., totalled 55 days, or 27 per cent. on 200 days. The consumption of carbons amounted to 360 carats, or 8 to 9 carats per 100 feet drilled, which at 80s. per carat gave a cost in loss of diamonds alone equal to 7s. per foot. Wages (including overseer) were 7s. 7d. per foot; sundries, 9d. per foot; or a total cost of 16s. 5d. per foot, to which must be added interest on £3000, the capital cost of the plant.

In Pennsylvania particulars of ten holes bored in the lower coal measures in the year 1895 show that—

> The total depth bored in the ten holes was 4577 feet.
> The average depth of the holes was 457 feet 7 inches.
> The average cost per foot was 5s. 9d.
> The average rate of boring was from 13 feet 2 inches to 26 feet 9 inches per shift of ten hours.

In Natal, during the year 1890, four Government drills (three hand and one steam-worked) bored a total depth of 5621 feet, chiefly through coal-bearing rocks, at a cost of 5s. 9d. per foot, without allowing anything for depreciation. Of this depth the steam-driven drill accounted for 1945 feet 2 inches at a cost of 7s. 11½d. per foot, which compares favourably with results obtained in other parts of the world. The loss of carbons during 1890–91 being only at the rate of 4⅗d. per foot, which, considering the number of intrusive sheets of doleritic rock penetrated, was a highly satisfactory result. In the year 1891–92 the cost of 6171 feet bored was 5s. 8d. per foot, of which 7d. per foot was for loss of diamonds. In the summer and autumn of 1906 the writer put down several holes in the coal-bearing rocks of northern Natal, the deepest of which was 1000 feet, none being shallower than 400 feet, at a cost of 13s. 6d. per foot for the first 600 feet and 20s. per foot for the next 400 feet, which price included transport of the drill by train from Johannesburg, and carriage by ox waggon across 20 to 25 miles of veldt. The terms of agreement are appended, as they are likely to be of use to young mining engineers in framing similar contracts.

An Agreement made and entered into this —— day of ——, by and between Messrs. ——, hereinafter called the Company of the one part, and the Diamond Drilling Syndicate, Limited, hereinafter called Contractors, of the other part.

The said Contractors agree as follows, subject to the provisions herein contained, and in manner set forth :—

1. To bore, with one or more steam diamond drills, two or more holes, $2\frac{1}{16}$ inches in diameter, giving a core $1\frac{3}{8}$ inches in diameter, on the Company's property, situated in the district of ——.

2. To bore two or more holes, at a point fixed upon by the Company or its duly authorised representative, to a depth of three hundred feet, and, at the option of the said Company, to continue the holes to a depth of 600 feet (six hundred feet), should they require such to be done.

3. That the said boring operations shall be at the sole expense of the Contractors, who shall provide all the necessary machinery, labour, and appliances, fuel and water, for carrying out the work expeditiously.

4. To take all possible precautions to preserve all cores coming from the bore-holes, and to prevent others than their employees from seeing the same, and to hand over all such cores to the Company or its duly authorised representative whenever called upon to do so, and further to keep all drilling operations and results secret.

5. In consideration for which the Company agrees:—

For every foot drilled, measuring from the surface to a depth of six hundred feet, 13s. 6d. per foot drilled.

In the event of the Company deciding to continue the bore-holes beyond a depth of six hundred feet, but not exceeding one thousand feet, 20s. per foot, such payment to be made as per Clause 6 hereof.

6. To pay at the rate agreed upon at the completion of every 100 (one hundred) feet, or any fraction thereof that may remain at the completion of each bore-hole. Such payments to be subject to retentions as per Clause 7 hereof.

7. The Company shall have the right to retain 10 (ten) per cent. of all moneys due to the Contractors on each bore-hole, until such times as the bore-hole has been satisfactorily completed or abandoned as per Clause 9 hereof, but any balance due on any bore-hole shall not be withheld for more than fourteen days after the completion or abandonment of the bore-hole from which the money has been withheld.

8. It is hereby mutually covenanted and agreed as follows:—

That if boring operations be suspended by order of the Company, or its duly authorised representative, or through the Company's negligence, then and in that case the Company shall pay the Contractors for each drill rendered idle the sum of ten (£10) pounds sterling per day demurrage for the period of such suspension; that is to say, that until instructions are given to the Contractors in writing for the drill or drills so rendered idle to resume work.

9. That in the event of the Contractors losing a bore-hole, and not being able to complete it to the full depth required by the Company, subject always to the provisions

contained in Clause 2 hereof, and provided that the fact of losing the bore-hole be due to the encountering of

(a) A cavity in the formation;

(c) A seam of running sand, through which it is not always possible to bore; or,

(c) Any other causes which renders drilling operations impossible;

then the Contractors shall not be held liable for the bore-hole lost, for which they shall be entitled to full payment as per Clause 6 hereof; provided, however, that in such an event the Contractors will, if so instructed by the Company, sink another bore-hole on the Company's property in a position which shall be pointed out to them, on the same terms and conditions as applied to the lost bore-hole.

This done and signed at this day of
*As Witness:—*

This done and signed at this day of
*Witnesses:—*

In the year 1892[1] the writer put down several holes by a hand-power machine in the same district as that mentioned above, the deepest of which was 132 feet, deducting the depth of surface soil and clay, &c. The core obtained was equal to 62·81 per cent. of the distance drilled; and the cost of drilling, excluding interest on capital, was 3s. 6d. per foot, calculated over three holes. The form of journal used by the writer is shown in Table XIX. (p. 171). A year before, a contractor carried out boring operations on some neighbouring properties, with the following results. A hand-power machine was used giving holes 1½ inches diameter:—

---

[1] See "Diamond Drilling in Natal," by R. A. S. Redmayne, *Trans. Brit. Soc., Min. Stud.*, vol. xv. pp. 135–142.

**Holes drilled--11.**
**Extreme distance apart—5 miles.**
**Total length drilled—1144 feet.**
**Total working days—50.**
**Hours worked per diem—10·5.**
**Average depth drilled per day—22·88 feet.**

**The Davis Calyx Drill.**—As has been pointed out (p. 156), the price of "carbons" has risen enormously of late years owing to the increased demand for these stones for diamond drills, and the loss of bort in some deep holes has been so great as to cause engineers to seek for a substitute.

The Davis steel cutter, which originated in Australia, has been found to be an efficient substitute in rocks of moderate hardness, and the American shot drilling process has given remarkable results when penetrating hard rocks.

The Davis Calyx apparatus comprises four parts (Fig. 99): A, The bit, which may be either a tooth crown for cutting soft rocks, or the plain pattern for the use of chilled steel shot in boring through hard rocks; B, the core barrel, which is a tube of a diameter greater than that of the rods, but equal to that of the body of the bit; F, the hollow drill rods which screw, through the medium of a reducing plug C, into the upper end of the core barrel, and D and E the calyx, which is a prolongation upwards of the core barrel, forming a cup or calyx, in which the heavy grains of large size are collected. When boring with a steel crown of large diameter, it would be difficult to carry to the surface all the chips of rock without vastly increasing the initial velocity of the water current, as a diminution in the rapidity of the upward rising or outflowing current would be caused by the great difference in size of core barrel and rods, hence many of the grains would be carried to but little distance beyond the head of the core barrel; as it is they fall back into the cup.

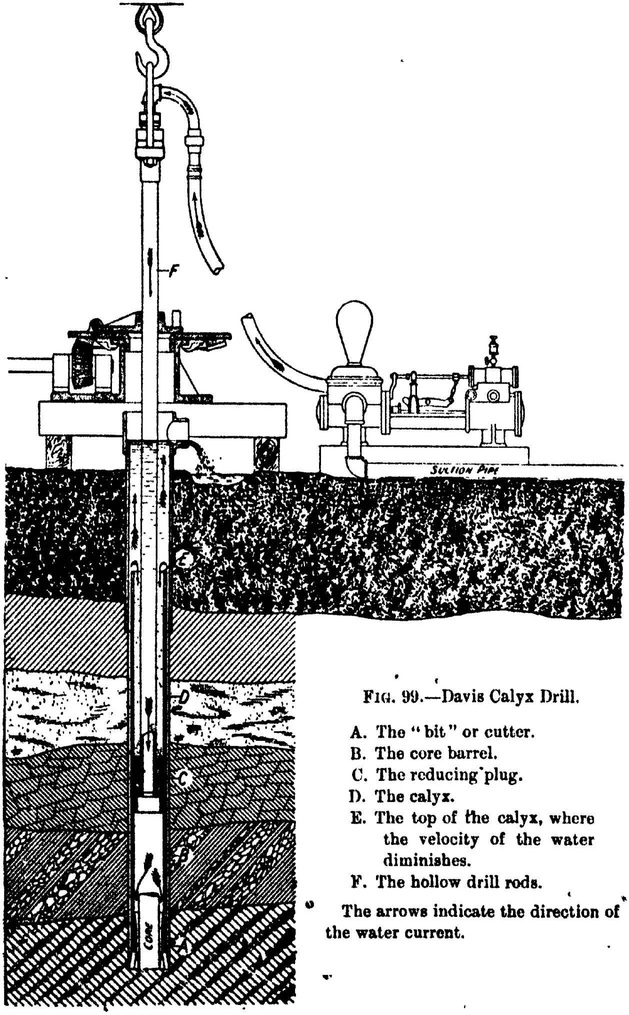


Fig. 99.—Davis Calyx Drill.

A. The "bit" or cutter.
B. The core barrel.
C. The reducing plug.
D. The calyx.
E. The top of the calyx, where the velocity of the water diminishes.
F. The hollow drill rods.

The arrows indicate the direction of the water current.

The toothed crown, which is usually about 1½ inches thick, is forged from specially tough steel, the teeth having an alternately inward and outward set, as in a saw, of about ⅛ inch, and the torsional strain of the rods applied by the slowly rotating gear (about 100 revolutions per minute) causes this cutter to move round with a jerky motion, and so chip as well as cut the rock. Crowns with detachable teeth are sometimes used, as shown in the photograph, Fig. 100, and have this advantage over the older form of crown that the teeth are easily removed when broken or in need of being sharpened, all that is necessary being the unscrewing of the retaining cylinder which holds the teeth firmly in the seats cut in the crown, and, as there are two or three positions in which each tooth can be set, they can be used until worn very low down.

FIG. 100. Crown of Davis Calyx Boring Apparatus showing removable teeth.

The toothed cutter can be employed for penetrating sandstones and shales of ordinary hardness; but when about to bore through more compact or crystalline rocks the toothed crown is replaced by another, a plain cylindrical steel tube with triangular notches cut in the bottom, which, running on chilled shot, cuts through the hard stratum much more quickly. The shot is produced by atomising molten steel and suddenly chilling it, which process renders it so hard as to allow of its even cutting glass. No. 6 size is that most commonly used. It is fed in through a valve on the water hose (Fig. 101), and is carried down the hollow bore rods, and so passes under the plain bit, which is driven at a somewhat higher velocity than the toothed crown, from 10 to 20 more revolutions giving good results.

The great cutting power of the shot in hard rocks is evidenced by the fact that it has been used to bore through Canadian corundum rock, which defied the attempts of diamond drillers. In other respects the fittings do not greatly differ from those of the diamond drillers.

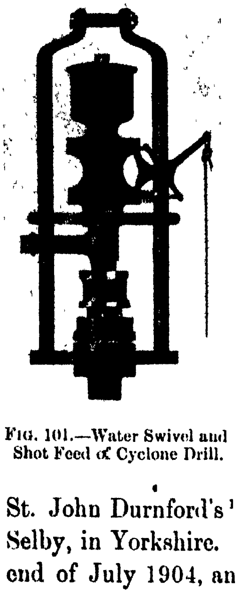


FIG. 101.—Water Swivel and Shot Feed of Cyclone Drill.

Several borings have been sunk in the United Kingdom with the Calyx drill. One at Langley Green, near Birmingham, to prove the extension of the "thick" coal, attained a depth of 1465 feet 6 inches, at an inclusive cost of £2073, 19s. It was commenced on July 25, 1904, and completed May 30, 1905. A good example of the work performed by this drill is given in Mr. St. John Durnford's[1] description of the deep boring near Selby, in Yorkshire. This hole was commenced about the end of July 1904, and completed about the beginning of August 1906, when it had reached the depth of 2371 feet. The diameter of the hole at the commencement was 18 inches, and was diminished from time to time owing to the insertion of lining tubes, the last 300 feet being 6 inches diameter.

---

[1] "Deep Boring at Barlow, near Selby," by H. St. John Durnford. *Trans. Inst. M.E.*, vol. xxxiv. p. 426.

**The Cyclone Drill Company** of Ohio, U.S.A., have also done good work with shot drilling. Figs. 101, 102, 103 represent some of the details of their plant. When cutting through the softer rocks they substitute "diamondite" for chilled shot, as it does not bed in the rock as the shot is found to do, and yet obviates the constant redressing necessary in the case of steel cutters.

**Obtaining Samples from certain Beds.**—There is one class of apparatus not yet mentioned which is of the highest importance, comprising those instruments sometimes termed "enlargers," which are more particularly used when boring holes by percussion with a chisel to a known bed or beds from which samples are required, or in those cases where, owing to the very tender or broken nature of a coal-seam, it is not possible to secure a core by either percussive or rotary boring. Fig. 104 illustrates a form of tool largely used for the purpose (perhaps more especially on the Continent of Europe than in the United Kingdom) of cutting samples from the wall of the hole. It consists of a tube carrying on its upper part an enlarging knife, which, mounted on a hinge, can be made to jut out against the side of the hole. This tube is of a diameter slightly less than that of the hole, and 5 to 6½ feet long, closed at the base. The weakening to the upper part of the tube, due to the opening which serves for the passage of the rock cut by the knife, is compensated for by an inner strengthening tube. In Fig. 104, *ab* is the cutting part, and *ac*, *bd* sloping edges which allow of easy vertical movement of the knife, and prevent obstacles stopping the descent or ascent of the tool. When this tool, replacing the cutting chisel or crown, has been

FIG. 102. -Spiral Shot Bit of Cyclone Drill.

lowered to the desired depth, the rods are rotated,

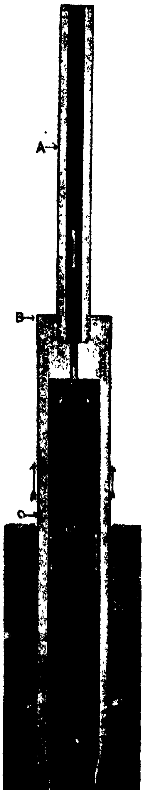


FIG. 103.—Section of Boring Arrangement of Cyclone Drill.

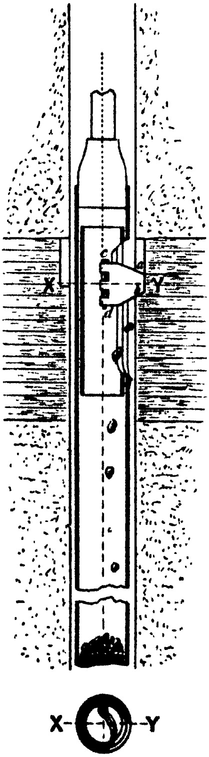


FIG. 104.—Enlarging Tool for taking Samples of Coal-seams or other Beds.

causing the blade to project and enables the hole to be cut upwards or downwards.

Experience has shown that tools of this nature are most effective in holes of small diameter.

**Particulars as to Boring in General.** *Surface Erections.*—When putting down a group of borings, one central steam-generating plant only will be necessary, and each machine may be fitted with its own steam-engine or electric motor, instead of, as is sometimes the case with a single plant, being driven by the locomotive type of engine. In all probability, if the work is on a large scale, electric driving will be found most suitable, especially if the prospecting operations are being carried on in search of petroleum, when, also, it will be advisable to remove the boiler as far as possible from the site of the holes.

If the work is to occupy a long time, especially under certain climatic conditions, the site of the boring operations should be covered in, in which case a boring tower will be reared vertically above the hole and subtended by the shops, &c. In order to allow of the raising of 15 metres of rods in one lift, on the Continent these boring towers are frequently as high as from 20 to 25 metres, and, though there they are usually constructed of wood, it will be found better to make them of some incombustible material.

*Lining and Size of Bore-holes.*—The operation of lining a bore-hole necessitates a reduction in the diameter of the hole from time to time. Hence there have to be included in the boring outfit sets of boring tools suited to these variations in size. The initial diameter of the boring is determined by the final diameter which one is desirous of obtaining, and the number of different sizes of tubing which it is calculated will be required from the depth of the hole and the nature of the strata to be penetrated.

The rotary methods of boring do not allow of such large diameter of hole as is frequently required when water or petroleum is the object of the search, the flushing water, when the hole is of large diameter, not being sufficiently rapid to enable the effective removal of the large amount of debris which is made in such cases; whereas by Fauck's system, with reversed current, holes 18 inches in diameter have been successfully bored.

When lining out a section of hole it is usual to employ Mannesman tubes for the purpose, with externally smooth joints, the lower tube having a cutting shoe, which assists the descent of the column of pipes. Another process, of more recent date, and known as cement tubing, has, however, the advantage of not reducing the diameter of the hole, and is at the same time quite water-tight. It is chiefly employed when passing through *absorbing* as opposed to *spouting* strata. A thin mixture of cement and water, known as "milk of cement," which sets quickly, is used as the injecting fluid; as it is injected the rods are gently and gradually raised until above the part where the side has fallen in or is weak, after which the rods and the upper part of the hole are washed with clear water, and boring through the portion so "crowned" is resumed. The greatest drawback to this process is its slowness.

*Recording of Results.*—It is most necessary that boring results should be carefully chronicled; the form of journal that the author adopts is given in Table XIX. as possibly serving as a guide to young engineers. Variations in the strata can nearly always be determined with considerable accuracy by carefully noting the changes in the colouration of the ascending water, and by making marks on the rods at the moment of change. When the outflowing water changes to inky black it is advisable, as this is an indication that coal has been struck,

## TABLE XIX.—*No. 3 Bore-hole.*

Put down on the Ballengeich Farm, Klip River County, Natal.

| Date, 1891. | Bored in each Bed. | | Thickness of Bed. | | Total Depth. | | Core Obtained. | | Nature of Strata. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|
| | ft. | in. | ft. | in. | ft. | in. | ft. | in. | | |
| Dec. 3, 4 and 5 | ... | | ... | | ... | | ... | | ... ... ... | Dismantling, shifting and erecting drill and tents at No. 3 site. |
| ,, 7 | 13 | 0 | 13 | 0 | 13 | 0 | nil. | | Stiff clay. | |
| ,, 8 | 16 | 4 | 16 | 4 | 29 | 4 | 2 | 4 | Very close-grained sandstone, with bands of arenaceous, carbonaceous, and micaceous shale. | |
| ,, 8 | 6 | 0 | | | 35 | 4 | 1 | 8 | Coarse-grained sandstone, very hard. | |
| ,, 9 | 2 | 0 | 8 | 0 | 37 | 4 | 4 | 8 | ,, ,, | |
| ,, 9 | 11 | 2½ | 11 | 2½ | 48 | 6½ | 6 | 4 | Very close-grained sandstone. | |
| ,, 9 | 1 | 0 | 1 | 0 | 49 | 6½ | 1 | 0 | Sandstone with thin bands of micaceous shale intermixed. | |
| ,, 10 | 2 | 3 | 2 | 3 | 51 | 9½ | 2 | 3 | Sandstone, grey and hard. | |
| ,, 10 | 3 | 10 | 3 | 10 | 55 | 7½ | 3 | 10 | Very close-grained sandstone, with innumerable wavy bands of black micaceous shale, false bedded. | |
| ,, 10 | 0 | 5 | 0 | 5 | 56 | 0½ | 0 | 3 | Coal, hard and bright, with thin dull bands. | |
| ,, 10 | 0 | 8¼ | 0 | 8¼ | 56 | 8¾ | 0 | 8¼ | Sandstone, with layers of arenaceous shale. | |
| ,, 10 | 0 | 3 | 0 | 3 | 56 | 11¾ | 0 | 1 | Coal, bright and anthracite. | |
| ,, 10 | 4 | 2 | 4 | 2 | 61 | 1¾ | 2 | 9½ | Sandstone, with micaceous shale. | |
| ,, 11 | 5 | 2 | ... | | 66 | 3¾ | 2 | 6 | Coarse white sandstone. | Lost 36 barrels of water in bore-hole; showing breaks in sandstone. |
| ,, 12 | 2 | 0 | ... | | 68 | 3¾ | 2 | 0 | ,, ,, ; very hard. | ,, 14 ,, ,, ,, ,, |
| ,, 14 | 6 | 7 | ... | | 74 | 10¾ | 0 | 8 | ,, ,, | Lost core in bore-hole, and 20 barrels of water. |
| ,, 15 | 6 | 7¼ | ... | | 81 | 6 | 4<br>5 | 2<br>2 | ,, ,, | Found lost core; stopped half day by heavy rain. |
| ,, 16 | 5 | 8¾ | ... | | 87 | 2¾ | 4 | 0 | ,, ,, | Stopped half day; Kaffirs carrying "mealie-meal." |
| ,, 17 | 6 | 5 | ... | | 93 | 7¾ | 3 | 0 | ,, ,, | |
| ,, 18 | 1 | 0 | 33 | 6 | 94 | 7¾ | 0 | 8 | ,, ,, | |
| ,, 18 | 3 | 9 | 3 | 9 | 98 | 4¾ | 2 | 0 | Black arenaceous shale. | |
| ,, 19 | 1 | 5 | 1 | 5 | 99 | 9¾ | 1 | 5 | Coarse white sandstone: very hard | Stopped for one hour by rain. |
| ,, 21 | 2 | 11 | ... | | 102 | 8¾ | 1 | 1 | Fine-grained sandstone. | Lost part of core in bore-hole; stopped one hour repairing pump. |
| ,, 22 | 1 | 1 | 4 | 0 | 103 | 9¾ | 1 | 3 | ,, ,, | Recovered core lost yesterday. |
| ,, 22 | 9 | 1 | ... | | 112 | 10¾ | 9 | 0 | Sandstone alternating with bands of black micaceous shale; false bedded. | |
| ,, 23 | 5 | 5 | 14 | 6 | 118 | 3¾ | 4 | 3 | | |
| ,, 23 | 3 | 7 | 3 | 7 | 121 | 10¾ | 2 | 0 | Coal. | |
| ,, 23 | 0 | 1 | 0 | 1 | 121 | 11¾ | 0 | 1 | Blackband. | |
| ,, 23 | 0 | 7 | 0 | 7 | 122 | 6¾ | 0 | 5 | Coal. | |
| ,, 23 | 0 | 4 | ... | | 122 | 10¾ | 0 | 3 | Black shale. | |
| ,, 24 | 0 | 4 | 0 | 8 | 123 | 2¾ | 0 | 3 | ,, ,, | |
| ,, 24 | 5 | 4 | 5 | 4 | 128 | 6¾ | 1 | 0 | Coal, bright, glossy, cubical towards bottom. | |
| ,, 24 | 0 | 2 | 0 | 2 | 128 | 8¾ | 0 | 1 | Blackband. | |
| ,, 24 | 2 | 11¼ | 2 | 11¼ | 131 | 8 | 2 | 4 | Coal, dull, anthracitic, with layers of pyrites. | |
| ,, 24 | 0 | 4 | ... | | 132 | 0 | 0 | 4 | Very hard, close-grained, greyish sandstone. | |

Core obtained, deducting depth of surface soil, clay, &c., equals 62·81 per cent. of depth of rock drilled through.

to at once cease boring, raise the rods, and extract the core. Then, when the rods have been re-lowered, to thoroughly scour out the hole, continuing the flushing until the water emerging therefrom is quite clear; then by boring through the seam a core will be obtained which on analysis will represent a more correct estimate of the value of the seam in respect of ash contents than if boring had been proceeded with in the first instance.

# CHAPTER VI

## SOME BORING PROBLEMS

**The Determination of the Amount of Deviation from Verticality and Deflection of Bore-holes.**—Bore-holes, especially those bored with turning tools, are never perfectly perpendicular, though the extent of the deflection varies considerably in different cases, depending on the inclination of the strata and the nature of the alternations of the strata. Thus in Fig. 105 a drill (*a*) is on the point of passing from a hard stratum (*b*) into a soft one (*c*), and as it will bore quicker in the soft than in the hard rock, the tendency will be for the drill to assume a position approximating to the dotted line. The bend will be in the other direction when the reverse is the case, and in some instances of deep borings, no doubt, the hole assumes a helical form.

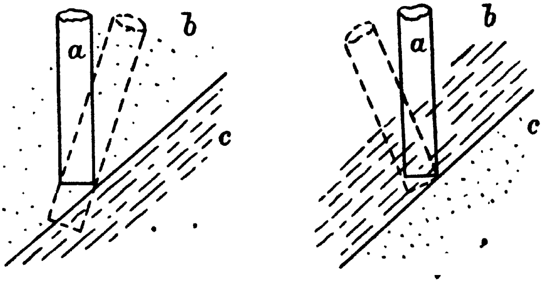


FIG. 105.

A hole put down by diamond drill at the Holyrood

Brewery, Edinburgh, showed a lateral departure of no less than 8 feet in a depth of 200 feet, as was proved by a drift, driven from the bottom of a well, intersecting it. The position of the hole underground was discovered by lowering bar magnets down it, and observing the effect of the same on a compass placed in the drift. At Sandhurst and Stawell in Victoria, Australia, the deviation from the initial direction of holes sunk by diamond drill was as much as from 30 to 75 feet in bores of 500 feet depth. It was the case of a lost bore at Stawell that led MacGeorge to devise his method of estimating the variation. The Lohse bore-hole, sunk perpendicularly with a diamond drill from the bottom of a shaft on the Simmer and Jack property (Transvaal), was found subsequently to be deflected 15 feet to the north in a depth of only 300 feet; in this case, as the strata were dipping to the south, the hole was across the measures.

**The Surveying of Bore-holes.**—There are several methods of determining the amount of the variation in the direction of a bore-hole; the six best known are, however—

1. Nelten's.
2. M'Farlane's.
3. Otto's, and others of a like character.
4. Meine's.
5. MacGeorge's.
6. Marriott's.

1. *Nolten's Instrument.*[1]—This invention of Herr G. Nolten of Dortmund, in Germany, which was one of the earliest methods devised for determining the deflection from verticality of bore-holes, is based on the fact that

---

[1] *Trans. N. of E. Inst. M.E.*, vol. xxix. (1879), p. 61.

liquids always maintain their natural level, and that if the liquid be hydrofluoric acid it will record the variation of level by etching on glass. Suppose Fig. 106 represents a glass vessel, the bottom being flat and the sides at right angles thereto, and into this is poured a liquid composed of, say, one part of hydrofluoric acid to four of water. If this instrument be placed in an inclined position, so that the surface of the liquid assumes the form of an inclined plane *ab*, and it be kept still for about half-an-hour, the level of the liquid will be etched on the glass; then if some of the liquid be poured out and the vessel placed horizontally, the surface of the remaining liquid will constitute a plane *cd*, the line of which will, after the lapse of some time, be, as before, etched on the glass. Drawing *ae* parallel to *cd*, there is formed a right-angled triangle *abe*, the angle *bae* being the angle of deviation from verticality.

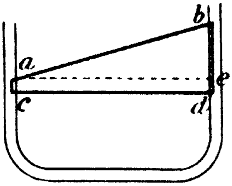


FIG. 106.

Fig. 107 illustrates the form of instrument used. It is constructed of brass with the exception of *a*, which represents a series of gutta-percha rings for taking up the shock in lowering and raising the instrument. In order to determine the *direction* of the declination, the glass vessel with the etching liquid is fitted into a ring which is rigidly connected with a compass, and having found the line of inclination (etched on the glass), the whole combination (glass, ring, and compass) is inclined in this plane, and the direction in a horizontal position of this line read off by degree marks on the ring, and at the same time the compass bearing; the difference of these readings being the magnetic bearing of the line of inclination. The mechanism itself, shown in Fig. 108, is fixed by means of a rod into the space *cd* (Fig. 107). The needle *e* is clamped by means of a stop-watch *f* acting on the lever *g* after sufficient time has been allowed for it to settle; *h* represents the glass vessel containing the etching liquid, and *i* the middle plate on which the compass needle, set high, rests.

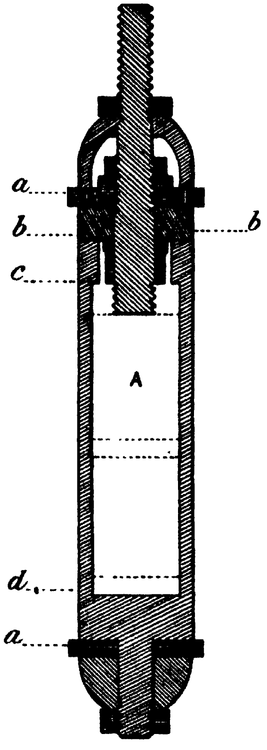


Fig. 107.

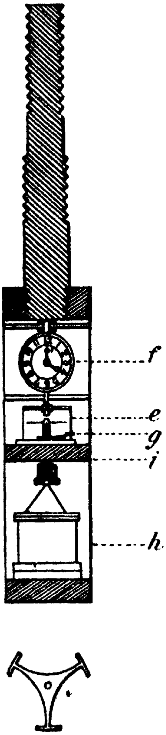


Fig. 108.

Nolten's Stratameter.

The position occupied by the mechanism in the brass casing is indicated by the dotted lines in Fig. 107.

Though an imperfect instrument, remarkable and startling results have been obtained with it. In the summer of 1874 the Gustav Adolph bore-hole, near Dieuslaken, was sunk by rotary boring and stopped at a depth of 750 feet, being tubed all this distance. Experiments were carried out with Nolten's apparatus, which gave the following results:—

At a distance of 200 feet the hole showed an inclination of 2° from vertical.
" " 300 " " " 3¾° "
" " 430 " " " 8¼° "
" " 750 " " " 47° "

At another boring near Leith, in Holsten, for 328 feet the hole was perpendicular.

At 656 feet it had a visible inclination.
" 984 " the inclination amounted to 3°.
" 1640 " the inclination was small.
" 2624 " the inclination was only 1° from vertical, and this it retained to a depth of 3280 feet.

It is interesting to note that this hole was proved to have followed a twisting or spiral course, like the rifling of a gun, for at 1640 feet the bearing was N.N.E., whereas at 2296 feet it was N.N.W.

2. *M'Farlane* placed a steel pipe, screwed on to the end of the boring rods, within another short steel pipe, the bottom of the inner pipe being open whilst that of the outer one was closed; the annular space between the pipes he used as a mercury bath, on which was floated a gutta-percha arrangement carrying a magnetic needle. Two iron wires passing up the inner tube were bared up to a point an inch above the mercury, beyond which they were insulated, and each was joined by an insulated copper wire passing up the bore rods to the surface, where they were attached to a tangent-galvanometer and battery. The action of this apparatus is simple. The

bare iron wires dip into the mercury more or less, according to the inclination of the hole, and so vary the resistance of the magnetic circuit. The amount of deflection of the galvanometer on the rotation of the rods shows the inclination of the holes; the direction of the dip being determined in a somewhat similar manner by a wire carried up to the surface and connected with a magnetic needle.

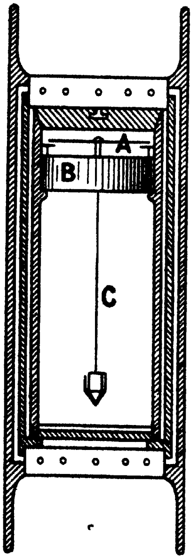


FIG. 109.—Otto's Stratameter.

3. *Otto's and Other Methods.*—P. Arrault[1] was one of the first to employ the compass for determining the dip of strata penetrated by bore-holes. Gothan, Koebrich,[2] and Vivian have all devised and used methods more or less similar, but they present drawbacks preventing their general or extensive use. The method of Otto of Hildesheim, devised a few years ago, seems more practicable. A rod of non-magnetic metal (bronze) is inserted in the suspended bore-rods at a small height above the crown, and carries in its middle (Fig. 109) a box guided by vertical grooves, preventing rotation; and ducts bored in the thickness of the metal allow of the passage of the water-current. This box, closed by a water-tight conical lid, is divided into three superimposed compartments, A, B, C. The compass is placed in A; in B is the clockwork on the alarm principle, which governs the mechanism for loosening and fixing the compass, and the drum on which is rolled the suspension thread for the

---

[1] *Revue Universelle des Mines*, 3rd series, vol. xii. 1890, p. 30.
[2] Tecklenburg, *op. cit.*, vol. cxi. p. 30, and Plate 4.

plummet, which hangs in the compartment C. It is this thread which registers the deviation of the bore-hole. The alarm being regulated in accordance with the time taken to lower the apparatus, allowing an ample margin, the crown and rods are lowered down the hole, and at the expiration of the period of time at which the alarm was set to work the fixing arrangement the freely swinging needle of the compass is clamped. When this happens the thread is unwound, and the plummet falling on a thin plate fixed on the bottom of the box, makes a dent, from which mark and the height of the box the amount of inclination of the hole can be calculated, the clamped needle recording the declination.

Some engineers, the Germans especially, have disputed the value of this method, and certainly it is open to grave criticism in that it determines the variation of the holes not by the core but by the core barrel, each turning movement of which, when breaking off or raising the core, causes some increase of error which is indeterminable; and the shaking of the rods may put the delicate mechanism out of gear, or, if imperfect in respect of water tightness, the clockwork is drowned and ceases to act. But, though failing to give good results in some districts in Germany, the apparatus has been used successfully in several instances elsewhere.

4. *Dr. Meine's Method.*—The recent invention of Dr. Meine of Berlin removes one of the chief causes of non-success inherent in the above apparatus. The arrangement for fixing the magnetic needle of the Otto apparatus is discarded, Dr. Meine using, to effect this purpose, a ball (Fig. 110) which is made to fall through the interior of the rods. This is pressed on the guide-seat *mm* by the water-current, the passage of which it opposes, forcing down the rod *l*, which is terminated at its base by

a conical piece causing, in moving down, the displacement of the eccentric *k*, and hence the rotation of the axis *h*, which, through the medium of the ring *g* and of the lever *f*, effects the raising up of the needle against the plate *p*. It is also so constructed as to assure the perfect water-tightness of the compartment containing the needles. The upper part *c* is fixed to the base by a screwed ring *d*, with the interposition of an indiarubber washer *e*. The rods *l* and *k* move through friction sockets as shown.

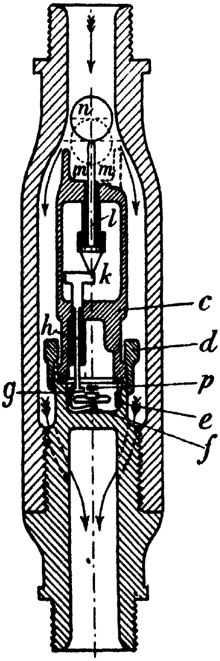


FIG. 110.—Meine's Stratameter.

The Stratameter Gesellschaft of Berlin accords to this apparatus many advantages over the older types, one of the most notable being the fact that it can be applied to holes of small diameter more easily than the older and somewhat similar forms. The moment at which the stratameter works can be determined at the surface by the increase of the pressure in the water of the force-pipe when the ball *n* is in the position shown in the sketch, and a sudden decrease when it is on the seat.

5. *The MacGeorge or Clinograph Method.*[1]—In this method a clear glass phial or "clinostat" is nearly filled with hot gelatine, the original formula for the preparation of which seems to have been lost since MacGeorge devised the apparatus. At one end *a* (Fig. 111),

---

[1] For a detailed account of this apparatus see *Engineering*, March 13, 1885.

it contains a magnetic needle in suspension, and in the upper bulb *b* a plummet consisting of a fine rod terminating below in a plumb of solid glass and attached above to a diminutive bulbous float, the whole being very carefully adjusted to the specific gravity of the gelatinous liquid. In the lower bulb the magnetic needle is also held up by a glass float. The small glass tube passes through an air-tight cork and screw at the upper end, the glass bulb *a* terminating the glass cylinder *e*, whilst *b* is a bulb terminating the small glass tube *d*; *c* is an air-tight cork and screw capsule, and *f* is a cork into which the lower end of the inner glass tube passes, preventing the escape of needle and float.

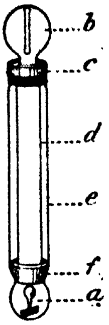


Fig. 111.—MacGeorge's Clinostat. (Lupton's *Mine Surveying*.)

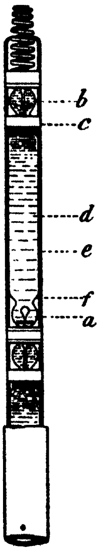


Fig. 112.—MacGeorge's Clinostat in its Protecting Tube.

The clinostats are heated, enclosed within a brass protecting tube (see Fig. 112), and lowered by line or rods into that part of the hole which it is desired to test; and sufficient time having been allowed for the liquid to cool and congeal, the apparatus is drawn to the surface, and the inclination and azimuth at the time of congelation determined by placing the clinostat in the same position which it occupied at the time of congelation in the bore-hole. The phial or clinostat with its congealed contents is placed within the sheath (1) of the instrument shown in Fig. 113, termed a clinometer; the upper bulb (2) of the phial is brought into the field of vision of the two cross-visioned microscopes (3 and 4), there being vertical lines drawn upon the object-glass of each microscope. The phial is revolved in its sheath, and the arm (5) is moved along the arc (6) by the tangent worm (7) until the plummet (8) is made perpendicular as viewed from each microscope, *i.e.* parallel with the vertical lines on the object-glasses.

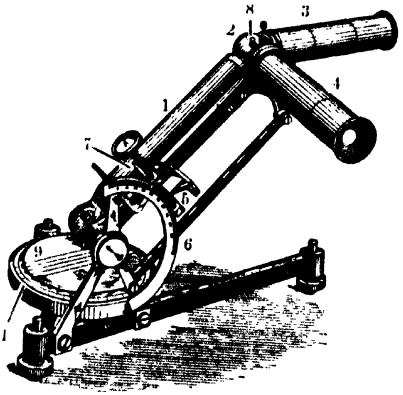


FIG. 113.—MacGeorge's Clinometer.
(Lupton's *Mine Surveying.*)

The phial is then in the same position in which it was when its contents were solidified. (9) is a revolving circular mirror with parallel lines engraved across it; on it the needle will be reflected. Now, seeing that the needle, when the clinostat was lying in the hole, pointed to the magnetic north, if the mirror is revolved until 270° of the graduated circle (10) is opposite the north end of the needle, and until the reflection of the needle is parallel with the engraved lines, the index at the other side of the graduated mirror frame gives the angle between the needle and the vertical plane of revolution of the phial,' which is the magnetic bearing of the inclined phial.

By applying this method at stated boring distances a bore-hole may be accurately surveyed, and this instrument, the invention of an Australian miner, has been largely used in Victoria, Western Australia, the West Coast of Africa, and elsewhere.

There are two disadvantages to be urged against the apparatus. The first is that it cannot be used in those cases where the increase in heat is great, as a high temperature prohibits congelation of the gelatinous liquid, consequently it may be said to be limited to holes of under 1000 feet in depth; and secondly, the fact that the receipt for making MacGeorge's gelatine composition has been lost.

6. *Marriott's invention*[1] consists in the use of electricity as a means of liquefying *in situ* a solid for recording readings, thereby eliminating the liability to error due to the motion of the instrument. His idea was to devise an instrument which would give check readings in one operation, instead of having to lower it down again and again, an operation occasioning a great loss of time, and hence considerable expense. This necessitated an instrument the variations recorded by which could be read at the surface as the instrument descended, therefore he had to resort to electricity as his means of conveying the varying records from the hole to the surface. But he has invented two kinds of apparatus, a continuous recording instrument for determining the variations in the amount of dip in a bore-hole, and an intermittent recording instrument for determining the variations in direction of the course of a bore-hole, and the variations of the amount of dip throughout such bore-hole.

---

[1] "Deep Bore-hole Surveying," by H. F. Marriott, *Trans. Inst. Min. and Met.*, vol. xiv. (1904-05), p. 255.

*The Continuous Recorder*, for determining variations in dip (Figs. 114, 115),[1] illustrate this instrument, in which A is a gun metal cylinder, B a hemi-cylinder of brass, *bb′* pivot screws supporting B, *aa′* metal plates, $b^2 b^2$ discs attached to the ends of B, C an ebonite disc, DD′ brackets fixed to B and carrying the vertical rod E, F a plumb bob pivoted to E and attached in such a manner that it can swing in one plane only; G is a switch arm attached to the top of the plumb bob, carrying at its upper end a strip of platinum. The movement of F

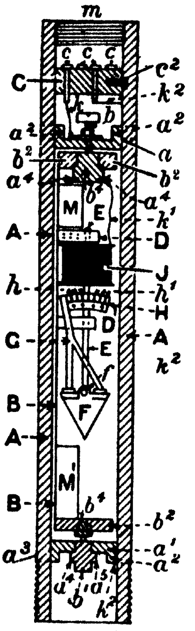


Fig. 114.—Marriott's Continuous Recorder.

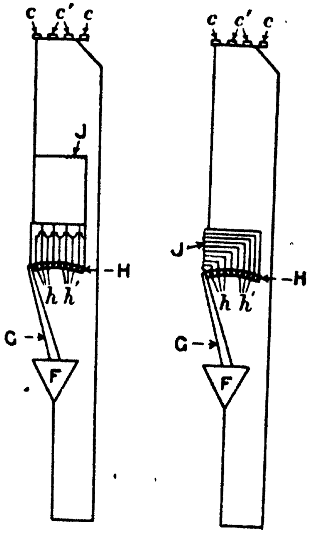


Fig. 115.

---

[1] The author is indebted to the Council of the Institution of Mining and Metallurgy for permission to reproduce the illustrations of Mr. Marriott's apparatus.

causes G to describe an arc about a centre *f*, which is the centre of oscillation of the plumb bob. H is a commutator fixed on the vertical rod E, and upon which the platinum strip on G presses gently. The commutator H consists of numerous metal contacts *h* of varying resistances, commencing at, say, a minimum and finishing with a maximum, interspaced with ebonite pieces *h′*. J is a resistance coil connected up with H, and MM′ are weighted segments which combined with the weight of the main portion of the rest of the instrument operating, when the outer casing A is tilted in any direction, to revolve the hemi-cylinder B on its pivots *bb′*, so that the switch G may move in a vertical plane. Two wires, *k* and *k′*, which pass the electric current through the instrument, may be connected up with a series of primary or secondary cells of known electromotive force, a galvanometer and a standard resistance box; the declination of the plumb bob F from the vertical can be determined by the galvanometer, the various resistances of the coil having previously been compared with those of the standard resistance box.

*The Intermittent Recorder*, for determining the variations in direction of the course of a bore-hole, and the variations of the amount of dip throughout the same, consists of A (Figs. 116 and 117), a copper cap; B and C, screw caps; E, lead washers; *aa*, two cylindrical pieces of ebonite through which the wires *dd′* pass; D, two concentric rings of brass, to one of which the wire *d* is attached, *d′* being fastened to another, these wires being located in grooves $a^2$ $a^3$ in the exterior of the tube, and insulated from the tube A and the plugs B and C. The ring F keeps the wires *dd′* in position, and G and H are terminals to which the wires are connected, *gg′* being washers, and J is a resistance coil to which G and H are attached.

K is a vertical needle rigidly attached to the nut *k*, which serves to screw up the same through the plug C. L is a magnetic compass balanced on the point of K, whilst *l* is the conical base to which L is affixed, M being a silver mirror fixed on top of the compass when it is desired to make a test. Before lowering into the hole, the magnetic compass L having been arranged in position on needle K, molten paraffin wax is poured into the tube until the lower portion of the compass attachment is well below the surface. This is allowed to solidify, and the top plug B being screwed on, the instrument is placed in a protecting casing, and the wires *dd'* connected to the source of supply of the electric energy through the medium of an electric cable. When the instrument has been lowered to the desired spot, a strong current is passed through the resistance coil J for a period long enough to melt the wax, when the needle will assume its true magnetic north and south position. The wax is allowed ample time in which to again solidify, then the instrument is drawn to the surface, and the direction of the dip ascertained by observing the declination of the mirror M from the horizontal, with regard to the direction of the compass L. Fig. 117 illustrates the adaptation of the marine compass, but this has since been further modified

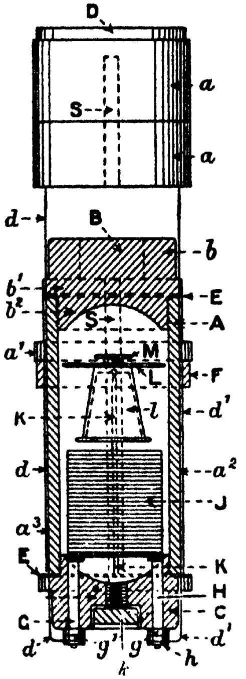


FIG. 116.—Marriott's Intermittent Recorder.

and improved. The inner ring and band has been replaced by a hemispherical cup O, in which the vertical needle carrying the compass is fixed. Paraffin wax is poured into the tube until it reaches about half-way up the outer side of the cup, and only just sufficient wax as is necessary to securely fix the base of the compass is poured into the cup itself.

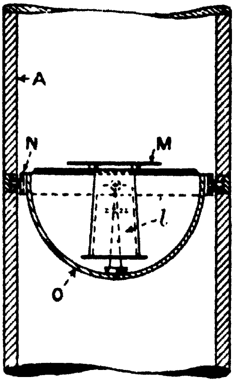


FIG. 117.

As pointing to the great value of having an accurate survey of a bore-hole, the instance of the two deep bores sunk by the Turf Mines, Ltd., in the Transvaal, may be quoted. Both of these holes showed considerable declination from the vertical. A survey of the east hole is given in Fig. 118 as being the deepest. The actual depth of the reef from the surface at the point where it was struck was 3910 feet, the distance bored being 4802 feet, or 892 feet more than the vertical depth, though 43 feet short of the calculated depth of the reef below the top of the bore-hole. Marriott's instrument was used to survey these holes.

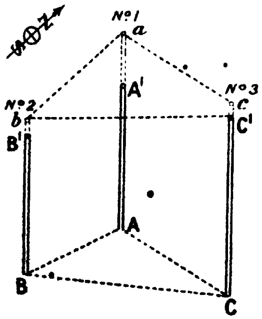
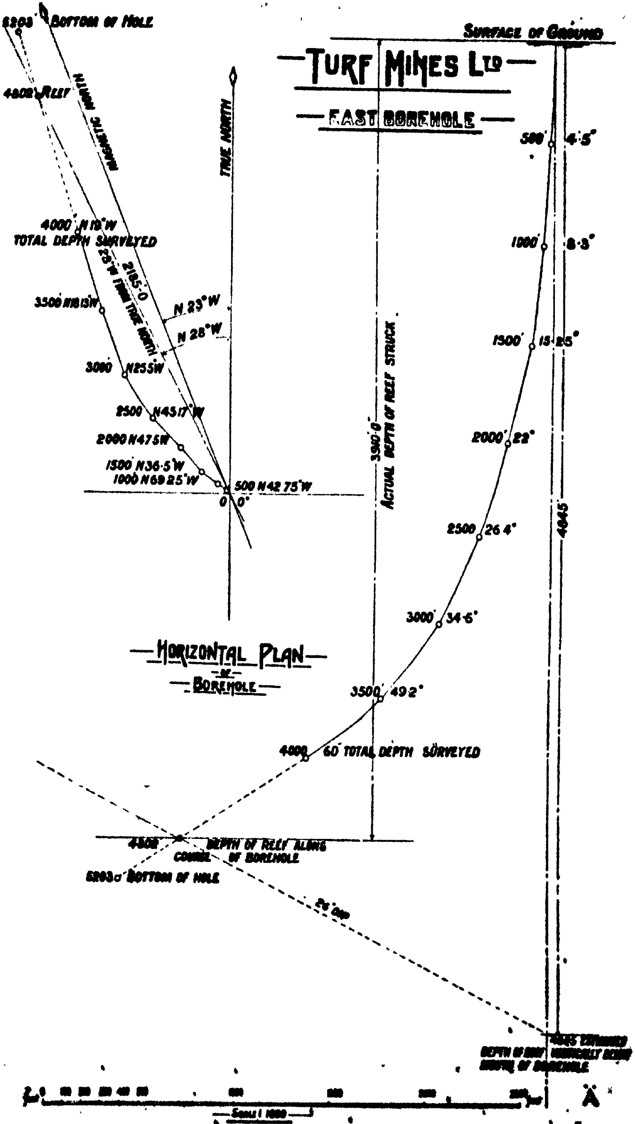


FIG. 119.

**To determine the Strike, Dip, and true Thickness of Coal-seams by Boring.** *Determination of Strike and Dip.*—Having put down three bore-holes in such a position that they form, roughly, an equilateral triangle, reduce the depths of the holes as from a datum



IG. 118.—Plan and Section of East Bore-hole sunk by the Turf Mines Ltd., Transvaal

line (this can be done by levelling); so that if $aA$, $bB$, $cC$ (Fig. 119) represent the holes as bored, the points A′, B′, C′ are in the same horizontal plane.

Then suppose at No. 1 hole the depth $A'A = 160$ yards.
" " 2 " " $B'B = 150$ yards, and that this hole is 300 yards due south of No. 1.
" " 3 " " $C'C = 200$ yards, and that it is distant 350 yards in a direction S. 50° E. of No. 1 hole.

Then the strike and dip of the seam within the area A′B′C′ can be determined either graphically or by calculation, always supposing geological disturbances to be absent. Let Fig. 120 represent the relative position of the holes.

Then[1] $a^2 = b^2 + c^2 - 2bc \cos A'$;
$\therefore \quad a^2 = 350^2 + 300^2 - 2\,(350 \times 300) \cos 50°$,
so $a = 278$ yards.

The difference of level between the seam at No. 2 and No. 3 holes is 50 yards, and $278 \div 50 = 5{\cdot}66$, or a dip from B′ in the direction of C′ of 1 in 5·56.

To find the level course or strike proceed along the line B′C′ until a point L is reached, where the seam is at the same depth as at A′, that is, 10 yards deeper than at B, and $5{\cdot}56 \times 10 = 55{\cdot}6$ yards, or the distance that L is from B′. LA is the line of strike, and the dip is at right angles to it, in this instance in a right-handed direction. The course of LA and of the dip could be taken by compass-bearing, or determined by calculation. Thus—

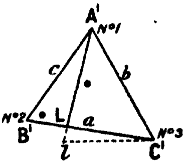


FIG. 120.

By trigonometry—

$$\frac{\sin A'}{a} = \frac{\sin B'}{b}$$

$$\frac{\sin B'}{350} = \frac{\sin 50°}{278},$$

---

[1] See *Euclid*, Book II., props. 12 and 13.

multiplying through by 350,

$$\sin B' = \frac{350 \sin 50^\circ}{278} = \cdot 965,$$

and the angle of which this is the sine = 75°.

Therefore the angle $B' = 75^\circ$.

It is then necessary to find the length of LA'.

In the triangle A'B'L we know that—

$$A'B' = 300.$$
$$B'L = 55{\cdot}6.$$
$$\text{Angle } B' = 75^\circ.$$

That is, two sides and the included angle is known, and

$$A'L^2 = A'B'^2 + B'L^2 - 2A'B' \times B'L \cos B' ;$$

$$\therefore \quad A'L = 290{\cdot}61 ;$$

and to find the angle LA'B' (or $\theta$),

$$\frac{\sin \theta}{B'L} = \frac{\sin B'}{A'L} ;$$

$$\therefore \quad \sin \theta = \frac{B'L \sin B'}{A'L} = 10^\circ \, 37',$$

*i.e.* A'L is S. 10° 37' E. of A',

which is the bearing of the strike from which the bearing of the dip is calculated. The dip is at right angles to the line of strike, and the reduced depth of the boreholes have shown that it is in the right-handed direction.

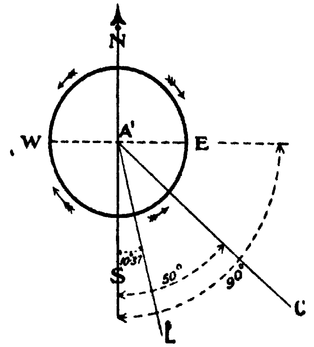


FIG. 121.

Therefore by Fig. 121—

$$90 - 10 \cdot 37 = 79^\circ\ 63'.$$

So the bearing of the dip is N. 79° 63′ E. In order to arrive at the amount of the dip, draw (see Fig. 120) from the point *l* and at right angles to LA′ the line *l*C′. Determine the length of this line, and dividing the same by the difference of level between the points *l* and C′.

$$\frac{lC' \text{ in yards}}{40 \text{ yards}} = x.$$

so 1 in $x$ will be the amount of dip.

*Determination of true Thickness of the Seam.*—There are two ways in which this can be done, the algebraical and the trigonometrical methods.

*Example.*—Suppose the dip of a seam is 1 in 6, and

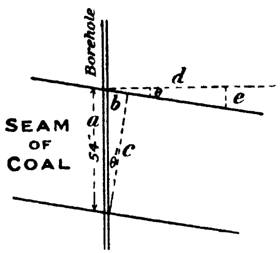


FIG. 122.

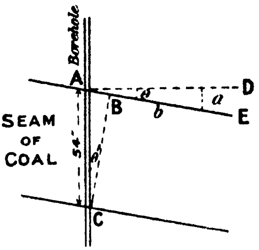


FIG. 123.

the thickness, as proved by a vertical boring, is 54 inches, required the true or perpendicular thickness of the seam?

In Fig. 122—

as $d$ is to $e$, so is $c$ to $b$,
and $d$ is 6 times $e$,
so $c$ is 6 times $b$;

$$\therefore\ c = 6b,$$
and $a^2 = b^2 + c^2$,
or $54^2 = 36b^2 + b^2$;
and $b^2 = \frac{2916}{37} = 78 \cdot 8$,
hence $b = 8 \cdot 878$,
$$\therefore\ c = 53 \cdot 268.$$

**Or by trigonometry (Fig. 123)—**

$$AC = 54'',$$

$$\tan DAE = \frac{a}{b} = \frac{1}{6}.$$

$\theta$, the angle of dip is the angle DAE, and because the triangles DAE and ACB are similar triangles

$$\text{the angles } DAE = \text{the angle } ACB\,;$$

and having that $\tan\theta = \frac{1}{6}$, from the mathematical tables it is found that the angle $\theta = 9^\circ\ 28'$.

$$\text{Again}\quad \cos\theta = \frac{BC}{AC};$$

$$\begin{aligned} \therefore\quad BC &= AC\cos\theta \\ &= 54 \times \cdot 986 \\ &= 53\cdot 24. \end{aligned}$$